UNCLASSIFIED

AD 419198

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

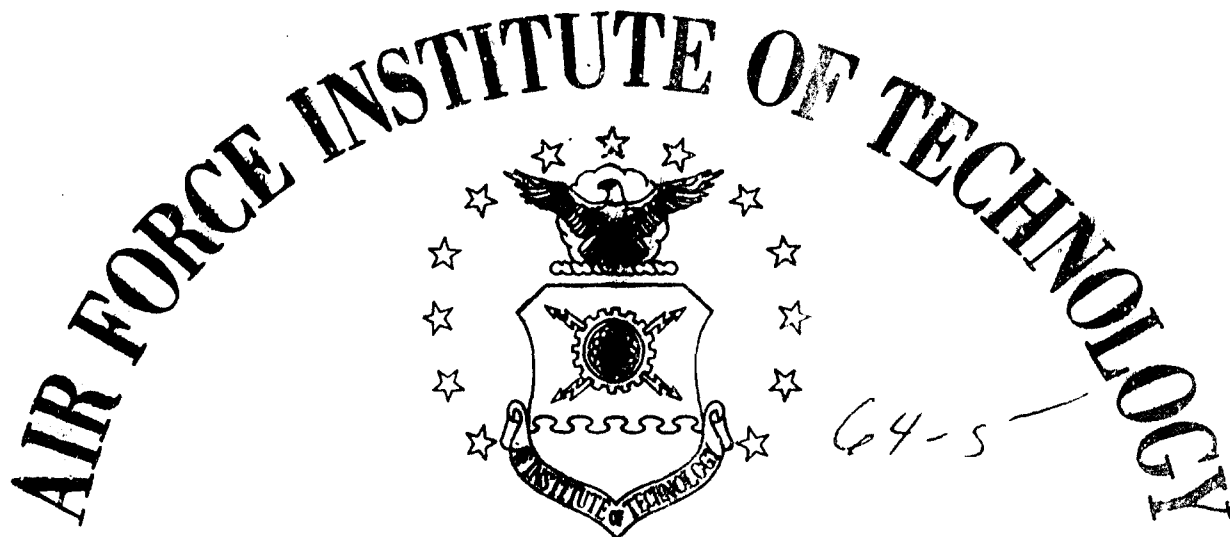# AIR FORCE INSTITUTE OF TECHNOLOGY

64-5

AIR UNIVERSITY
UNITED STATES AIR FORCE
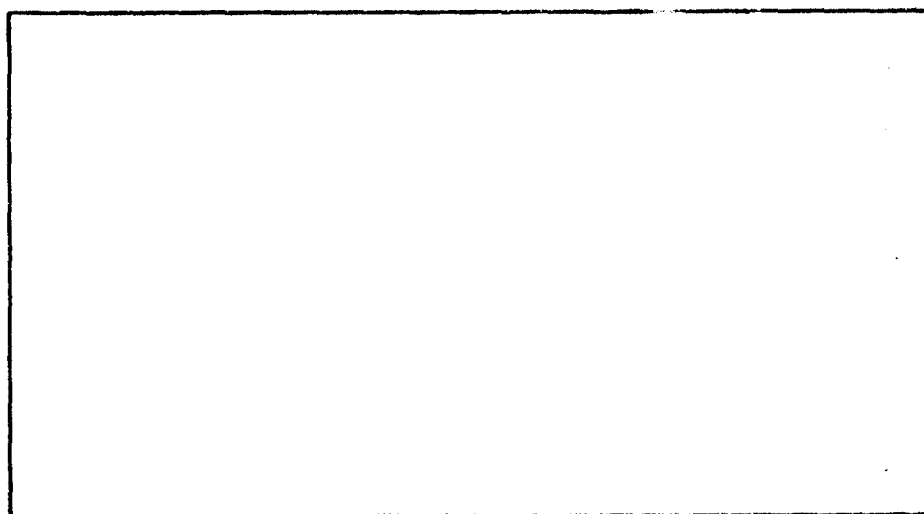
SCHOOL OF ENGINEERING

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

AN INVESTIGATION INTO PATTERN
INVARIANCE RECOGNITION CAPABILITIES
OF THE
HUMAN VISUAL SYSTEM

THESIS

GE/EE/63-11   William L. Harrison
               Capt   USAF

AN INVESTIGATION INTO PATTERN INVARIANCE

RECOGNITION CAPABILITIES OF THE

HUMAN VISUAL SYSTEM

THESIS

Presented to the Faculty of the School of Engineering of

the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

By

William Lavern Harrison, B.S.

Capt   USAF

Graduate Electrical Engineering

August 1963

Preface

This report is the result of my attempt to gain a better understanding of how the human visual system functions in performing pattern invariance recognition. An engineering approach is used in this investigation. I feel that the use of engineering methods of investigation in seeking solutions of biolbgical problems may sometimes be more feasible and more productive than the use of biological methods of investigation. In the simulation of a complex biological system, the use of digital computers seems particularly valuable, since the many trial and error steps required in constructing a physical model are reduced to the testing, revising, and retesting of computer programs.

I wish to express my gratitude to Captain Matthew Kabrisky (Ref 4) for the development of the basic model of a cortical cylinder and for his assistance in writing the computer program. Also, I wish to thank my wife and children for their patience and understanding during the time spent in making this investigation.

William L. Harrison

Contents

List of Figures

Abstract

The purpose of this investigation is to find out how the human visual system performs pattern invariance recognition. A detailed study of the human visual system is made, a model of a portion of this system is derived, the model is simulated on a digital computer and tested to determine its pattern invariance recognition capabilities. The results indicate that the model recognizes patterns when translated slightly, rotated small amounts, or varied slightly in size and shape; however, its capabilities are far short of those of the human visual system. A recommendation is made for revising the model for further investigation.

I. Introduction

The human visual system is capable of recognizing learned patterns even though they have been translated in position, rotated through small angles, varied in size, or varied slightly in shape. Very little is known about the methods used by the visual system in achieving this pattern invariance recognition. The purpose of this research is to gain a better understanding of the functioning of the visual system in pattern invariance recognition.

This investigation does not include the functions of color vision or binocular vision, but only two dimensional black and white pattern recognition. No attempt is made to prove or disprove existing theories on the functioning of the human visual system.

It is intended that any simulation of any portion of the visual system will lie within the physical limitations of this system. To be considered an adequate simulation, a model of the visual system must be capable of recognizing learned patterns despite translation, small angles of rotation up to 25 degrees, large size variations, and slight shape variations of these patterns.

A wealth of literature has been written on the human visual system. Clinical studies and pathological investigations of the visual system have been carried on for many years. In recent years a great deal of

scientific research has been conducted on various types
of pattern recognition devices. This has led to much
written material on various methods of achieving pattern
recognition. No attempt was made to read all of this
material, but only enough to gain a basic understanding
of the detailed composition of the human visual system.

Any research leading to a better understanding of
the functioning of the human visual pattern would be use-
ful to persons in many fields. Astronomy, photography,
ophthalmology, physiology, medicine, and computer design
are only a few of the fields which would benefit from
this knowledge. The visual system is the most important
single source of information for the brain, since some
38% of all fibers entering or leaving the central nervous
system do so by way of the optic nerves (Ref 8:301).

There are several possible methods which could be
used in investigating the visual system. Surgical and
electro-chemical techniques could be used to probe the
visual system of suitable guinea pigs, trace the paths
of information flow, and observe the visual effects of
blocking certain portions of the visual system. This
method would be more suited to a physiologist than an
electrical engineering student.

A second method would be to use a combination of
optical and photographic techniques to build a machine
of lenses, filters, screens, and pattern storage devices,
patterned after the visual system, in an attempt to

GE/EE/63-11

duplicate the pattern invariance recognition capabilities
of the eye-brain system. This method would require an
extensive knowledge of the field of optics and some ex-
pense in the purchase of optical devices.

A third method would be to use digital computer sim-
ulation techniques to simulate the eye-brain system in
an attempt to duplicate the pattern invariance recog-
nition capabilities of this system.

The third method mentioned above was the one used
in this investigation. The primary reason for selecting
this method was one of economy, since the only cost was
the purchase of computer time. Computer simulation was
also a more convenient method for an electrical engineer-
ing student to use.

The plan of attack followed in this investigation
may be divided into five steps. In chronological order
they are:

1. Conduct a study of the subcortical portions of
   the human visual system.

2. Conduct a study of the cortical portions of the
   human visual system.

3. Derive a model of the human visual system and
   program this model on a digital computer.

4. Develop testing procedures and test the model
   on a digital computer.

5. Evaluate the data obtained from testing the model
   to determine the pattern invariance recognition

capabilities of the model.

These five steps were followed in this same chronological order in writing this thesis.

II. <u>The</u> <u>Subcortical</u> <u>Portions</u> <u>of</u> <u>the</u> <u>Human</u> <u>Visual</u> <u>System</u>

Included in the subcortical visual pathways are all
the nerve structures from the retina of the eye to the
cortex of the brain (see Fig. 1). The primary path for
information flow from the eyes to the cortex is from the
retinae of the eyes to the optic chiasma via the optic
nerves, then to the lateral geniculate nuclei via the
optic tract, then to area 17 of the visual cortex via
the visual radiation. There are some side branches from
this main path, but they are more related to the various
mechanical movements of the eye than to the act of pattern
recognition. Only the primary paths from the eyes to the
cortex of the brain will be discussed in this chapter.

The retina is the membrane at the back of the eye
which acts as the actual photoreceptor organ. It is
composed entirely of nervous tissue and blood vessels,
and is actually an outgrowth of the frontal end of the
brain formed during the early period of embryonic life.
Light entering the eye through the cornea and lens and
falling on the retina, causes it to emit electrical
pulses, which, when transmitted to the brain, result in
the act of perception or vision. The two types of elements
in the retina which act as photocells are the rods and
cones, so named because of their shapes. The rods are
more sensitive to light than the cones and are the
primary source of night vision. The cones are associated

5
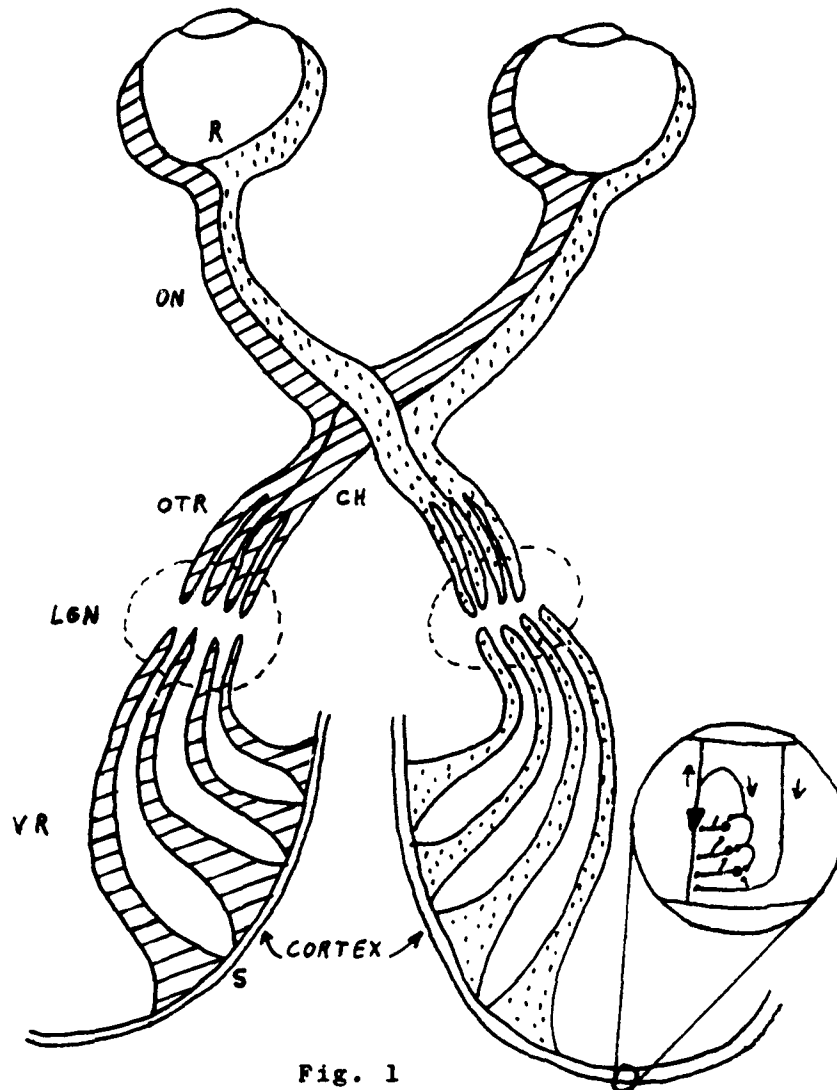
Fig. 1

Subcortical Visual Paths

This is a diagram of the subcortical portions
of the human visual system, including the
retinae (R), optic nerves (ON), optic chiasma
(CH), optic tracts (OTR), lateral geniculate
nucleus (LGN), visual radiation (VR), and
striate area (S) or area 17 of the cerebral
cortex. An enlarged section of the cortex is
shown.

(From Ref 8:289)

with day vision. Rods and cones are interspersed through-
out the retina with two exceptions. There are no rods or
cones at the point where the optic nerve is connected to
the retina. This results in a blind spot in the field
of view. There is also a small pit or depression at
the point near the center of the retina in which only
cones are located. This pit is called the fovea and
is located at the center of the field of vision. This is
the center circle in the retina in Fig. 2, although it
actually occupies a proportionately smaller area in the
retina than drawn in the figure. Outside the fovea, the
retina is made up of both rods and cones, with the rods
becoming more dense and the cones more sparce moving
towards the periphery of the retina. The fovea is the
area of highest visual acuity. Here the cones are packed
very close together and are 1 to 1.5 microns in diameter.
Near the periphery of the retina the diameter of the cones
is 6 to 8 microns. In the eyes of certain species possess-
ing extremely high visual acuity, for example, the
golden eagle, the thinnest cones in the fovea are approx-
imately 1/3 micron in diameter (Ref 8:226).

In Fig. 2 is seen a mapping of the field of view in
each retina. Each retina is divided into quadrants, as
is the foveal area in each retina. The extreme left
and right edges of the field of view (a, d, b, and c) are
the monocular portions of vision and appear on only
one retina. The remaining portions of the field of view,

Fig. 2

Subcortical Visual Centers

This diagram shows the topographic representation
of the field of view and the left and right
retinal surfaces in the lateral geniculate nuclei
and area 17 of the cerebral cortex. The vertical
meridian (VM) and the horizontal meridian (HM)
are shown in each visual center.

(From Ref 8:431)

8
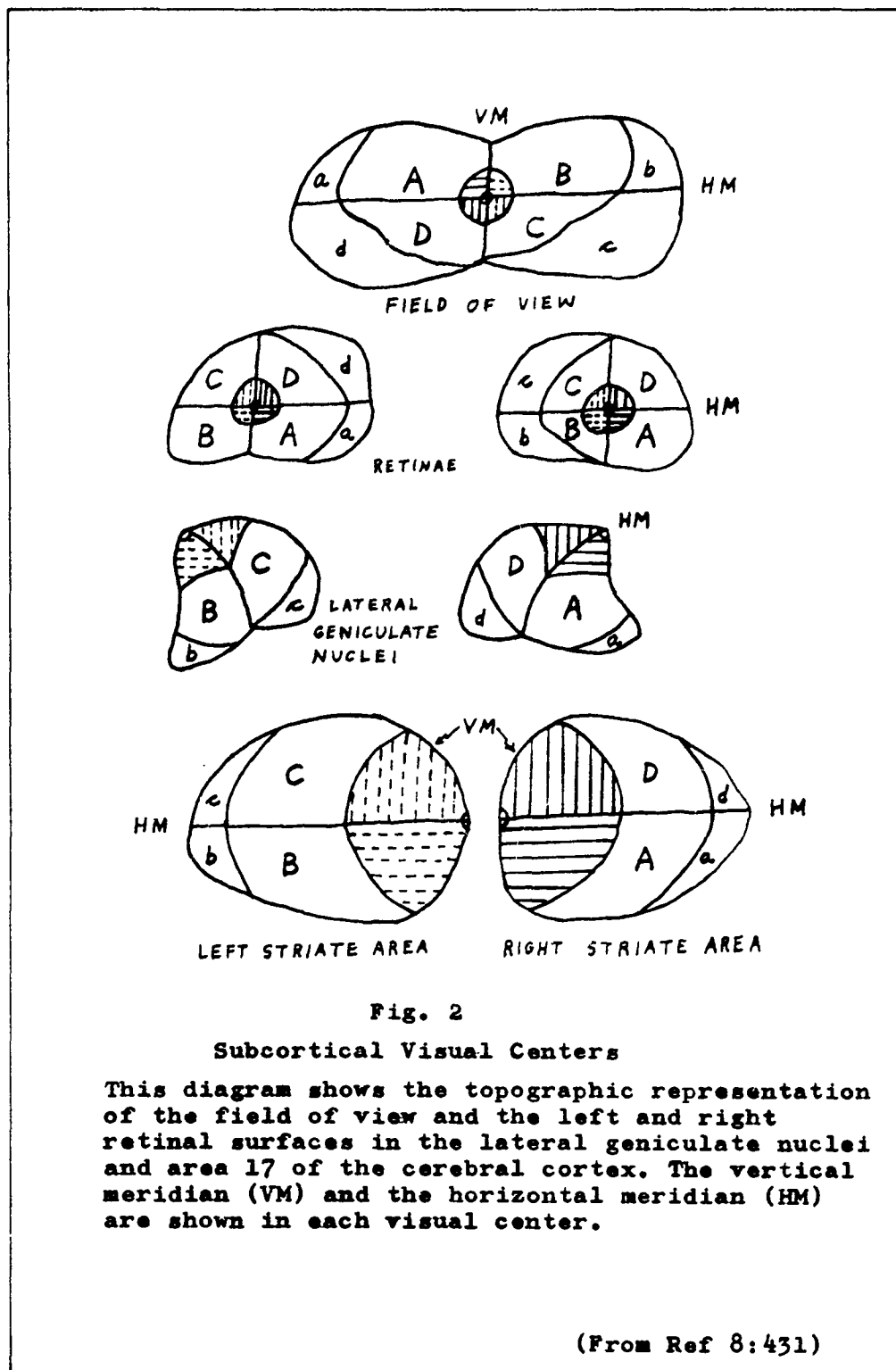
quadrants A, B, C, and D, are projected to corresponding
quadrants on each retina. Similarly, the four quadrants
in the center of the field of view are projected to
corresponding quadrants in the fovea of each retina. The
number of rods and cones in the retina is approximately
10^8, and the number of fibers in the optic nerve is
approximately 10^6, thus, each receptor cell cannot send
individual information to the brain. In the peripheral
region there are many rods or cones connected through
integrating neurons to single nerve fibers, but in the
rodless center of the fovea, where detailed vision origin-
ates each cone is connected through a neuron to a single
fiber of the optic nerve. In this small rodless area
measuring about 500 microns across, there are about
35,000 cones. This area corresponds to 1 degree 50
minutes of arc in the field of view, yet it is probably
the most important part of the retina. The fact that
each individual cone in this area can send information
to the brain is undoubtedly related to the detailed
vision occurring in this area.

The 10^6 fibers from the retina are bundled together
to form the optic nerve. Each of these fibers is actually
the axon of a retinal neuron. The two optic nerves meet
at the optic chiasma, where the fibers from the nasal
half of each retina cross and join the fibers from the
temporal half of the opposite retina to form the optic
tracts (see Fig. 1). Thus the left optic tract is

composed of fibers from the left half of each retina

and the right optic tract is composed of fibers from

the right half of each retina. The optic tracts continue

on to the lateral geniculate nuclei in the thalamus of

the midbrain.

The fibers of the optic tract terminate in six

layers in the lateral geniculate nucleus. Fibers from

corresponding points in each retina terminate in super-

posed positions in alternating layers. As shown in Fig. 2,

the mapping of the retina is preserved in the lateral

geniculate nuclei. The amount of area in the lateral

geniculate nuclei devoted to fibers from the fovea is

proportionately larger than the area of the retina

occupied by the fovea. In the lateral geniculate nuclei

the horizontal meridian has been shifted slightly, as

shown in Fig. 2. Also, a proportionally smaller space

is devoted to the fibers from the nasal periphery of the

retinae, which is the area of monocular vision. The area

devoted to the fibers from the upper quadrants of the

retina is larger than that devoted to those from the

lower quadrants.

Each fiber from the retina terminates in axosomatic

synapses with a small nest of large neurons in the lateral

geniculate nuclei. Fibers originating in these nests

of large neurons comprise the paths, known as the visual

radiation, which continue from the lateral geniculate

nuclei to the cortex. Several types of neurons are found

10

in the lateral geniculate nucleus. The primary type is
composed of the large neurons upon which the vertical
fibers terminate. There are also smaller neurons, called
"association cells", each of which is synaptically
related with approximately 12 of the large neurons
(Ref 8:369-370). The most significant feature of the
lateral geniculate nuclei is that the mapping of the
retina is preserved both in the fibers which enter the
lateral geniculate nuclei and in the fibers which depart
the lateral geniculate nuclei in the visual radiation.
As seen in Fig. 1, the fibers of the visual radiation
lead directly to area 17 of the cerebral cortex. Here
they terminate at points which topographically conform
to the mapping of the retina (see Fig. 2). The portion
of area 17 representing the fovea is proportionately
larger than the area of the fovea in the retina. Also
the peripheral portion of area 17 is proportionately
smaller than the peripheral portion of the retina. In
the retina the foveal units (cones) are very small, but
they gradually increase in size in the peripheral regions.
In area 17, where space is less severely restricted and
the function of information processing demands a greater
mass of the nervous substance in each unit, exactly the
opposite is true. Here the units gradually increase in
size from the peripheral to the foveal areas. The size
of area 17 in man is, on the average, 2613 square
millimeters. Since the area of the retina is approximately

350 square millimeters, the ratio of its area to that
of area 17 is roughly 1 to 7 (Ref. 8:490).

The most significant fact gained from the study of
the subcortical portions of the human visual system is
that the retina is connected point by point to area 17
of the cerebral cortex in a manner which makes possible
conformal mapping of the retina in area 17. The right
half of each retina is mapped in area 17 of the right
occipital lobe and the left half of each retina is
mapped in area 17 of the left occipital lobe of the
brain. The mapping of the fovea is accomplished by each
cone being connected to a corresponding point in area
17; thus, an image falling on the fovea could be
projected in great detail to area 17. A closer look at
the terminations in area 17 of fibers from the lateral
geniculate nuclei, and at further cortical portions of
the visual system, will be taken in the following
chapter.

III. Cortical Portions of the Human Visual System

In the preceding chapter, the fibers from the retina were shown to terminate in area 17 of the cerebral cortex. Before taking a closer look at these terminations, a discussion must be made of the general structure of the brain.

The brain consists of an upper main part, the cerebrum, and a lower small part, the cerebellum. Only the cerebrum is concerned in this investigation. The brain is enclosed in three membranes. The outer membrane, which is relatively thich and tough, adheres to the cranium. The inner two membranes are thin and soft. The innermost membrane closely adheres to the surface of the brain, penetrating all dents and depressions of the cerebral surface. It contains the blood vessels which are the principal avenue used to supply blood to the brain. The brain is composed of two kinds of substance, grey matter and white matter. Most of the grey matter forms the relatively thin outer shell of the brain called the cortex. This cortex is composed of countless neurons and their thin fibers, and of a dense network of minute blood vessels and capillaries. This is apparently the portion of the brain where the "higher" functions of information processing are performed. The white matter forms the inner or subcortical portion of the brain and is composed principally of nerve fibers

of varying thickness. These fibers could be considered
as transmission lines connecting various portions of the
cortex.

The cerebrum, which is the largest and uppermost
part of the brain, is seperated into a left and a right
hemisphere. The lobe at the rear of each hemisphere,
the occipital lobe, is the location of area 17 (see Fig.
3). The cerebral cortex was mapped into functional areas
and numbered by Brodmann. The fibers of the visual rad-
iation terminate wholly within area 17 of each side of
the brain. There is no crossover of fibers in the vis-
ual radiation. The fibers from the left lateral genic-
ulate nucleus terminate solely in area 17 of the left
occipital lobe, and those from the right lateral genic-
ulate nucleus terminate only in area 17 of the right
occipital lobe (Ref 8:403-405).

The cortex in area 17 is thin compared with other
cortical areas. The thinnest part of area 17 is in the
foveal regions. Area 17 is, on the whole, much richer
in neurons than the remainder of the cerebral cortex.
Also, the size of its neurons is much smaller, the space
between its neurons less, and the distribution of its
neurons more uniform than in other cortical areas. A
vertical section through the cortex in area 17 shows
eight separate parallel layers, five of which are rich
in neurons and three of lesser density (Ref 8:496).
These layers are parallel to the cortical surface and

14
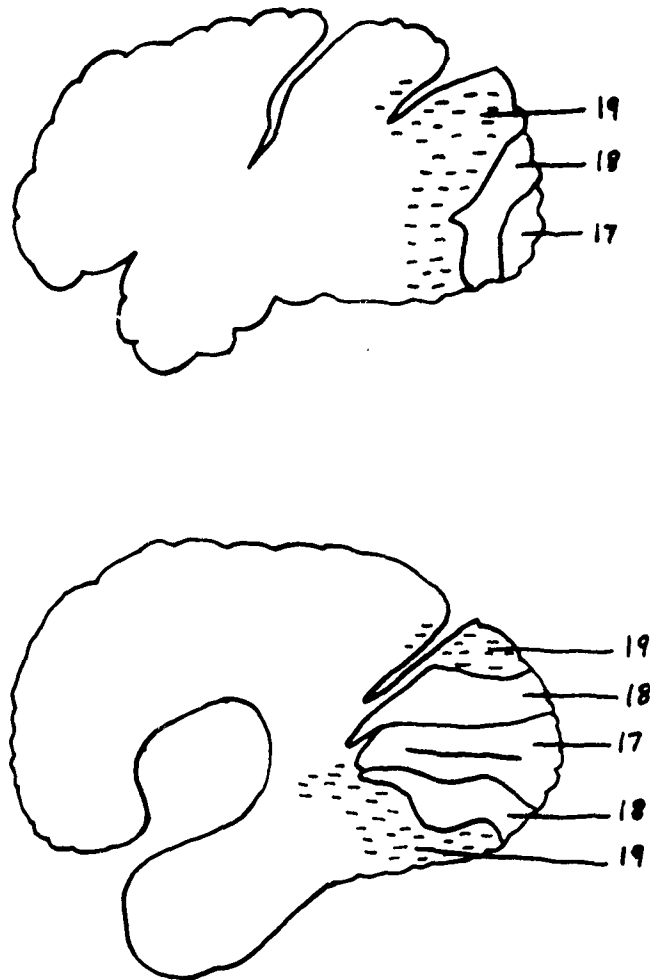
Fig. 3

Cortical Visual Centers

This is a sketch of the human cerebral cortex
showing the location of the visual centers, area
17, area 18, and area 19, as numbered by
Brodmann. The upper figure is a side view of the
left hemisphere and the lower figure is a cross
section, taken lengthwise through a vertical
plane, of the right hemisphere.

(From Ref 8:492)

are numbered 1, 2, 3, 4a, 4b, 4c, 5, and 6, with layer 1
being the outermost layer. The fibers of the visual
radiation enter the cortex from underneath and pass
through layers 6, 5, and 4c to terminate in layer 4b
(Ref 8:519-521). Layer 4b is composed of neurons which
are connected by a dense network of short horizontal
fibers. Although the fibers of the visual radiation are
the principal ones terminating in layer 4b, there are
indications of other fibers terminating in this layer
(Ref 8:523).

In layer 1 there are few neurons, but there are
many fibers from neurons in lower layers. In layer 2
there are several types of neurons with short fibers,
one of which has vertical fibers extending up into layer
1 and down as far as layer 4b (Ref 8:527). In the foveal
portion of area 17 in an adult Rhesus Macaque monkey,
there are neurons in layer 2 with axons which descend
to the subcortical matter (Ref 8:531). The neurons in
layer 3 are of several types, which in general resemble
those in layer 2. However, some of them have fibers
which descend to the subcortical portion of the brain
(Ref 8:527).

The neurons of layer 4 appear more diversified than
those in other layers. They vary a great deal in the
shape, size, and distribution of their bodies and in
their dendritic and axonal expansions (Ref 8:527). The
most conspicuous neurons in this layer are large solitary

16

ganglion cells whose bodies and dendrites are mostly
oriented horizontally or obliquely. Their axons de-
scend toward the subcortical substance. Whether all
of these leave area 17 is questionable (Ref 8:527).
Another type of neuron in layer 4 has vertical fibers
which fuse superposed segments of layers 4a, 4b, 4c,
and 5 into functional units whose elements are acti-
vated simultaneously (Ref 8:527). Other large neurons,
residing in the zone between layers 4b and 4c, have
dendrites which radiate in all directions and inter-
connect relatively large segments of these sublayers
into functional units (Ref 8:527).

Layers 5 and 6 are also populated by numerous neu-
ron varieties. Although their detailed connections
are not well known, it seems that more neurons here
are oriented in a horizontal direction than in the
layers above (Ref 8:531).

As stated before, the terminations of fibers of
the visual radiation are in layer 4b of area 17. Each
fiber spreads horizontally in this layer for short dis-
tances. In the foveal portion of area 17 of a baby
Rhesus Macaque monkey, the horizontal spread of an
individual fiber measures 100 to 150 microns. This,
computed for the foveal portion of area 17, would give
at least 10,000 to 15,000 independently stimulable
functional units to each vertical foveal half. This
is in fair agreement with the number of cones populating

the foveal territory of the retina (Ref 8:533). This

seems to indicate the connection of each cone in the

fovea to a corresponding functional unit in the foveal

portion of area 17. In the same foveal portions of the

human area 17, the number of units would be correspondingly

larger in order to satisfy the greater number of central

foveal cones in the human retinae.

There are fibers from area 17 which pass through

the subcortical substance before re-entering the cortex.

These fibers have been traced by making minute lesions

in area 17 of living monkeys. The axons from the neurons

destroyed in these lesions will degenerate and may be

traced to their terminations when the monkey is later

sacrificed. Through this technique it has been found

that there are three categories of interconnecting fibers

from area 17. In the first category are the short intra-

cortical fibers originating from the neurons in area 17

and terminating in the nearest neighboring neurons. These

fibers, primarily in layer 4, have been discussed before.

They connect each minute area to its immediately surround-

ing area within area 17. These fibers do not descend

to the subcortical part of the brain.

The second category of fibers is composed of short

subcortical fibers. From each minute point in area 17

a great number of these fibers descend to the subcortical

substance, where they immediately spread in four directions

and eventually re-enter the cortex in the same area 17.

Through these fibers each particular point of area 17 is connected both ways with a fairly large portion of area 17.

The fibers in the third category are somewhat longer subcortical fibers than those in the second category. From each point in area 17, they descend to the subcortical substance. They continue beneath the cortex to area 18 and area 19 where they re-enter the cortex and terminate (see Fig. 3). These fibers branch considerably at their terminations, thus, the area of these terminations is much larger than the area of origin in area 17. Also the large areas of termination in area 18 and area 19 of fibers from any two neighboring points in area 17 are overlapping. Briefly, each minute territory of area 17 is connected to a larger territory of areas 18 and 19, with a reciprocal overlapping of adjoining units. Since no other cortical areas of the same cerebral hemisphere receive fibers from area 17, it seems that the primary stream of transformed retinal impulses from area 17 reaches, as the next station, areas 18 and 19 (Ref 8:439). The connections from area 17 to areas 18 and 19 indicate that the point to point projection of the retina, heretofore observed in the visual system, is now lost. Undoubtedly, a more complex relation exists here.

Fibers from area 17 of one cerebral hemisphere to area 17 of the opposite cerebral hemisphere are either

entirely absent or very poorly developed. Equally
uncertain are direct connections from area 17 to parts of
the midbrain. There also seems to be no direct fibers
from area 17 to other principal sensory and motor
regions of the same or opposite hemisphere of the
brain (Ref 8:440).

The sense of vision in the brain is bound to the
occipital lobes of both cerebral hemispheres. Area 17
appears to be the location of the visual sensations of
a more elemental character, such as the perception of
light and colors, and localization of external objects
in space. Areas 18 and 19 seem to be a material repos-
itory of complex visual functions, such as visual memory
of the shape, color, and movements of objects which
have been observed, and of the symbols or meanings of
these objects (Ref 8:453). Very little seems to be known
about the functioning of the visual centers of the
cortex or about the significance of the interconnecting
fibers in the functioning of these centers. It is
possible there are further connections from areas 18
and 19 to other areas of the cerebral cortex, although
no information on such connections was found in this
investigation.

Several significant facts have been gained from the
study of the visual portions of the cerebral cortex.
The fibers of the visual radiation terminate in layer 4b
of area 17. In the foveal portion of area 17, these

GE/EE/63-11

terminations indicate an independently stimulable
functional unit of the cortex for each fiber and thus
for each cone in the retinal fovea. Vertical fibers from
neurons in layer 4 of area 17 fuse superposed segments
of layers 4a, 4b, 4c, and 5 into functional units.
Both of these facts seem to indicate that the basic
functional unit of the foveal portion of area 17 is a
vertical, cylindrical section of the cortex. Adjacent
neurons in area 17 are connected by short intracortical
association fibers. From neurons in layers 2, 3, and 4b,
there are axon fibers descending to the subcortical
substance below layer 6. A majority of these fibers
spread in four directions and re-enter the cortex in
area 17. Others continue outside area 17 and re-enter
the cortex in areas 18 and 19.

This completes the study of the visual system.
The next step is to apply the information gained here
in the development of a digital computer simulation of
this system.

IV. <u>Computer</u> <u>Simulation</u> <u>of</u> <u>a</u> <u>Portion</u> <u>of</u> <u>the</u>

<u>Human</u> <u>Visual</u> <u>System</u>

This chapter includes the development of a model of
area 17, an explanation of a flow diagram of the computer
simulation of the model, and an explanation of the digital
computer program for the simulation of the model. The
goal it is hoped to achieve in this computer simulation
is to obtain a model, patterned after the human visual
system, which will possess the same pattern invariance
recognition capabilities as the human visual system.

The digital computer used in this investigation was
the IBM 1620. The maximum memory of 40,000 digits in
this computer placed a substantial restriction on the
simulation of the visual system. This limitation is not
alleviated substantially by even the largest contemporary
machines.

Since the retina is mapped point by point in area
17, it was assumed that very little pattern recognition
is performed in the subcortical portions of the visual
system.

A pattern falling on the retina is projected point
by point to area 17 by way of neuron output pulses. A
simulation of the visual system must include area 17 and
contain a method of feeding a pattern into this area 17
in the form of pulses. The basic functional unit of the
foveal portion of area 17 is postulated herein to be a

22

cortical cylinder, which is stimulated by neuron pulses from a single cone in the fovea. It was decided to represent the foveal portion of area 17 as a square screen composed of 100 cortical cylinders in a 10 x 10 array (see Fig. 4). Each of these cortical cylinders would represent a basic functional unit of area 17 which might be called a "super cell", since it is composed of many nerve cells. The neuron pulse rate input to this unit from a foveal cone was simulated by feeding a signal level, quantized in units from 0 to 100, into the unit. The amplitude of the signal would correspond to the intensity of the light falling on the foveal cone, since in the actual eye-brain system, input stimuli are coded into neuron pulse firing rate. Black and white patterns falling on the fovea and being projected to area 17 was simulated by feeding appropriate signal levels, representing white, into various units in the 10x10 array and by feeding a level of zero, representing black, into all other units in the array.

As shown in Fig. 4, the coordinates K and J were used to locate each unit in the array. A simple bar pattern would be presented to the array by feeding a level of amplitude 50 into the units indicated by an X in the figure and a level of zero into all other units. Storage or memorization of the pattern was made possible by gradually storing the applied level into the individual cells. The short connecting fibers between neighbor-
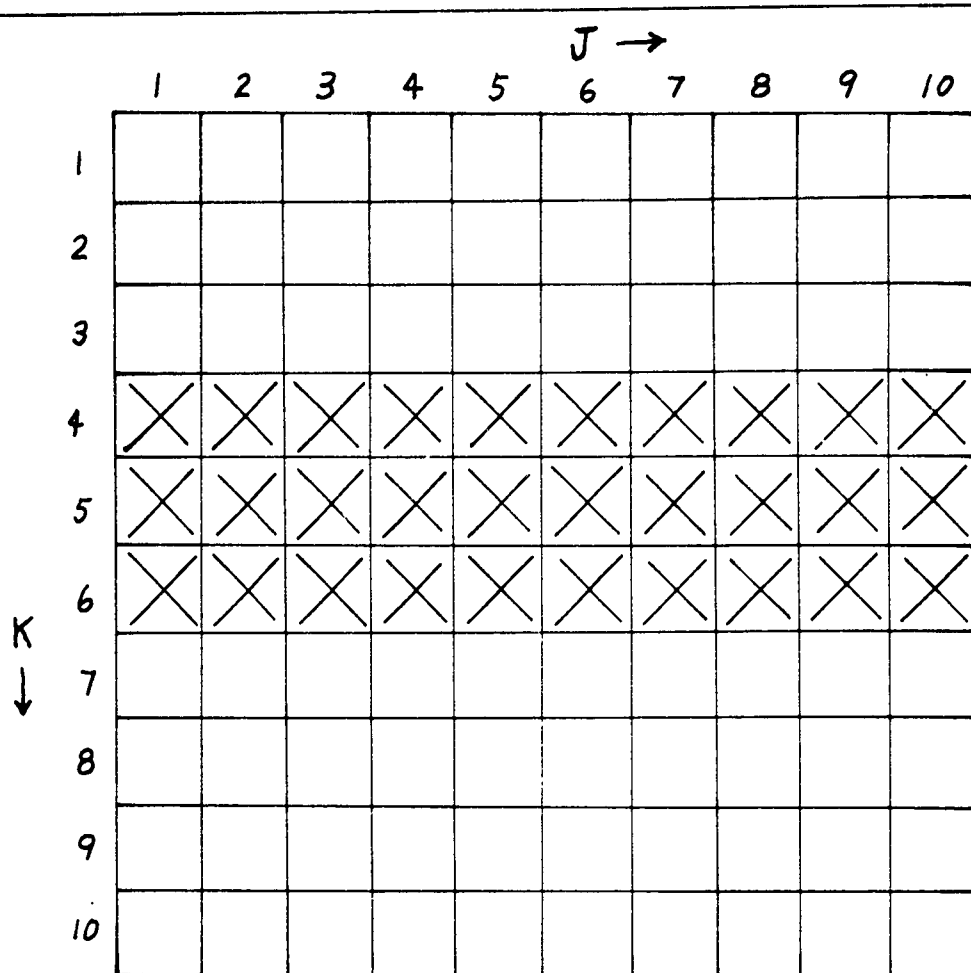
Fig. 4

Model of Area 17

ing neurons in area 17 were simulated by coupling each

of the cells in the 10x10 array with its four adacent

cells. Thus, a portion of the input to a certain cell

would be fed to each of its four adjacent cells. This

was the simulation of area 17 attempted here. The sub-

cortical interconnecting fibers between cells within

area 17 and from area 17 to areas 18 and 19 have not

been considered, although these are probably responsible

for the most sophisticated aspects of visual data process-

ing. It was decided to test this partial simulation of

area 17 for its pattern invariance recognition capabilities

before attempting further simulation of the visual system.

In Fig. 5 is shown a flow diagram of the digital

computer simulation of the 10x10 array of supercells.

The input, $P(K,J)$, is the 10x10 array of signal levels

representing a black and white pattern. The bar pattern

in Fig. 4 will be taken as this input and the level applied

to the cell in position (5,5) will be followed through the

flow diagram. This level for P(5,5) is 50 units (these

units are arbitrary and represent the physiological sit-

uation where light intensity is coded into pulse firing

rate in nerve cells.) which is the primary input to the

summer block. Also, there are four inputs to this block

from the four cells adjacent to cell (5,5). As shown in

Fig. 5, these are P(4,5), P(5,6), P(6,5), and P(5,4). The

blocks G1, G2, G3, and G4 are multipliers which may be

varied to change the degree of input coupling between

25
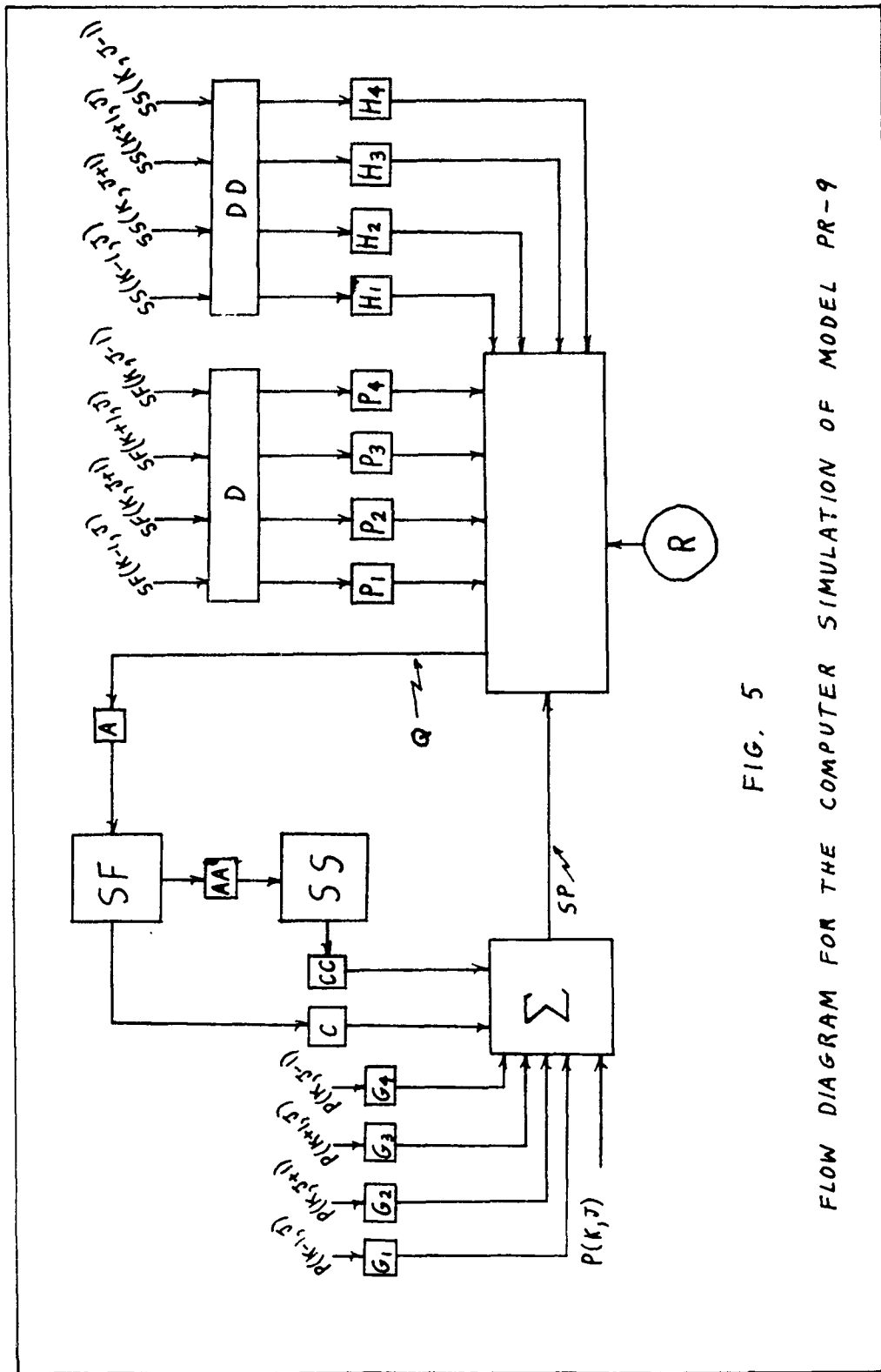
FIG. 5

FLOW DIAGRAM FOR THE COMPUTER SIMULATION OF MODEL PR-9

adjacent cells. If these multipliers are assigned a
value of 0.1, then in this pattern the coupled input to
cell (5,5) from each of these adjacent cells would be five
units. Thus, initially the total input to the summer
block is 50 + 20 = 70 units (assuming the feedback through
blocks C and CC is zero). The output of the summer block,
SP, is 70 units, which is fed into the next block. The
input R to this block is a reference signal, which will
be considered as zero. The other eight inputs to this
block will also be considered as zero initially.

The output of this block is called the error signal
and is designated as Q. This error is defined as

$$Q = R - SP - E\left[H_1 \cdot DD \cdot SS(K-1, J) + P_1 \cdot D \cdot SF(K-1, J)\right]$$
$$-F\left[H_2 \cdot DD \cdot SS(K, J+1) + P_2 \cdot D \cdot SF(K, J+1)\right]$$
$$-G\left[H_3 \cdot DD \cdot SS(K+1, J) + P_3 \cdot D \cdot SF(K+1, J)\right]$$
$$-H\left[H_4 \cdot DD \cdot SS(K, J-1) + P_4 \cdot D \cdot SF(K, J-1)\right]$$

Thus, Q, initially, is -70 units. The block A is
a multiplier which may be varied to control the feedback
amplitude. If A = 0.1, then the output of block A is
(-70)(0.1) = -7 units. Block SF is a 10x10 array in
which the feedback signal is stored. The signal of -7
units is stored in position (5,5) of this array. From
block SF there are two outputs, one through the multi-
plier block C to the input summer, and the other through

the multiplier AA to block SS. Block SS is a 10x10 array
in which is stored a portion of the signal from the SF
array. A typical value used for AA is 0.01, thus -0.07
units is initially stored in position (5,5) of the SS
array. From the SS block, the -0.07 units flows through
a multiplier CC and enters the input summer block. If
C and CC are set at 1.0, then signals of -7 units and
-0.07 units from the SF and SS arrays are fed back into
the input summer block. This process of storing a
negative portion of the input voltage to each cell in
the SF and SS arrays is carried out for each cell in the
10x10 array to complete the first iteration.

In the second iteration, the input from P(5,5) and
the four adjacent cells still totals 70 units, but now
the negative feedback signals are added to this, pro-
ducing a value of 62.93 units for SP. This is fed into
the second block along with the reference signal R, which
remains constant at zero. Now the other eight inputs
to this block are no longer zero. These inputs represent
coupling of the stored signals between adjacent cells.
The amount of this coupling is controlled by setting the
multipliers D and DD equal to 0.1. The multipliers P1,
P2, P3, P4, H1, H2, H3, and H4 are set equal to 1.0. In
this second iteration, the coupled signal from each
adjacent cell in the SF storage array will be -0.7 units,
and the signal from each adjacent cell in the SS storage
array will be -0.007 units. Thus, the value of Q in the

second iteration will be -60. 0102 units. From the mul-
tiplier A, the feedback of -6.0102 units will be stored
in position (5,5) in the SF array. This -6.0102 units,
added to the -7 units stored during the first iteration,
produces -13.0102 units as the feedback through C to the
input summer for the third iteration. Similarly, the
feedback from SS for the third iteration will be
-0.130102 units.

It can be seen that the negative of the input pattern
is slowly being stored in the SF array, and even more
slowly stored in the SS array. Also, the error signal
Q is slowly being reduced. This reduction of the error
signal to a small value is used as an indication that
the negative of the input pattern is well stored in the
SF array. After the negative of the input pattern is
well stored, at any later time when the same pattern is
used as an input, the error signal Q will be very small
on the first iteration. This will indicate recognition
of the pattern. If a different pattern is used as the
input, the value of Q will be larger on the first
iteration. The magnitude of Q will be an indication of
the degree of non-recognition of the pattern.

The flow diagram described above was programmed for
the IBM 1620 digital computer. The program, which was
written in Fortran language (slightly modified for use
at the Air Force Institute of Technology), is shown on
pages 78 through 80 in Appendix A. This program was

designed to permit the operator to control the degree of

coupling between adjacent cells for both the input signals

and the storage array signals. ⁱhe rate of storage may

also be varied by changing the multiplier constants A and

AA. The amount of feedback may be changed by assigning

various values to the constants C and CC. The capability

of obtaining a print out and punch out of the SF, SS, and

DE arrays after each iteration was included in the program.

The DE(K,J) array is a 10x10 array of the error signal Q.

An explanation of the computer program will now be

made. This may be followed by referring to the program

in Appendix A. The first statement gives the dimensions

of the input array, P(K,J), the fast storage array, SF(K,J),

and the error signal array, DE(K,J). The next four READ

statements set the amount of coupling between cells for

the input and storage of the input pattern. The following

PAUSE permits loading the cards for the input, P(K,J),

into the reader hopper. In the DO1 loop, the input pattern

is read into the computer. The PAUSE following statement

1 permits loading the cards for the fast storage array,

SF(K,J), into the reader hopper. The DO 2 loop then

reads this array into the computer. The PAUSE following

statement 2 and the DO 3 loop permit loading and reading

of the slow storage array, SS(K,J), into the computer .

Statement 31 contains the format for the input of these

three arrays.

The ITNO statement sets the first iteration number

30

equal to zero. B is the symbol for a positive value of
the error signal Q. Statement 52 sets B equal to zero
for the initial iteration. The letter U is the symbol
for the sum of the absolute values of all the error
signals, Q, in the DE(K,J) array. The statement follow-
ing statement 52 sets U equal to zero for the initial
iteration. The letters UU are the symbol for the sum
of the squares of the error signals in the DE array.
This is initially set equal to zero. The letters UUU
are the symbol for the algebraic sum of the error signals
in the DE array. This is also set equal to zero for the
initial iteration. The DO 4 loop is the basic iteration
of the program. This loop computes the error signal, Q,
for each cell in the 10 x 10 array from K=1 to K=N and
from J=1 to J=N. The value of N is set in statement
34 at 10, which is the largest value of K and J in the
array. The computed value of Q for each cell is then
stored in the proper position in the DE(K,J) array, and
at the completion of the DO 4 loop the DE array will
contain a value of Q for each of the 100 cells.

Statements 5 through 17 ensure that zero coupling
is made to cells on the perimeter of the array from
positions outside the array. Statement 18 and the five
following statements set the value of Q for each cell
equal to the reference signal, R, minus the total
pattern input, SP, minus the coupled storage signals
from the four adjacent cells. The next statement,

DE(K,J) = Q, then stores the computed value of Q into the
proper position in the DE array. The statements from
the IF(E*F*G*H) 69,4,69 statement through statement 4
perform the various summations of the errors in the
DE(K,J) array to obtain values for U, UU, and UUU. The
value of BB, which is the largest error signal in the
DE array, is also obtained in these statements. The
location of this largest error in the DE array is also
obtained and designated by L and M, which correspond
to the K and J coordinates of the array.

Following statement 4 a print out is made of the
iteration number, ITNO, the value of the largest error
signal, BB, the coordinates of this error signal, L
and M, the sum of the absolute values of the error
signals, U, the sum of the squares of the error signals,
UU, and the algebraic sum of the error signals, UUU.
Statements 100 and 101 give the format for the print
out of these error signals. The statement following
statement 101 increases the iteration number by one
integer. The following two IF statements provide external
control of the program at this point. If switch 3 is
on, the computer will go to statement 43, pause, then
proceed to statement 34. This permits an exit from the
series of iterations with the present data and permits.
new data to be read into the program and a new series
of iterations to begin. If switch 3 is off, the computer
will go to statement 53, where if switch 1 is on, a

print out of the SF array will be made. If switch 1
is off, statement 50 will be executed. This is the entry
into the DO 51 loop, which stores a portion of the DE
error array in the SF array and then stores a portion
of the SF array into the SS array. The computer will
now go to statement 52 and execute a new iteration. If
switch 1 is on, the SF array will be printed (statements
40 through 1001). Then, if switch 2 is on, a punch of
the printed SF array will be executed (statements 25
through 30). If switch 2 is off, no punch will be made
and the computer will print the SS array next (statements
26 through 141). Again, if switch 2 is on, a punch of
the printed SS array will be executed (statements 29
through 152). Next a print of the DE array will be made
(statements 153 through 142). This completes the printing
and/or punching of the storage and error arrays and the
computer will go to statement 50 and perform the DO 51
loop (storing the error array in the storage arrays),
then go to statement 52 and begin a new iteration.

The three external control switches provide several
options on the output of the computer. With all three
switches off, the only output will be the printing of
ITNO, B, L, M, U, UU, and UUU at the end of each iter-
ation. This permits the operator to monitor the error
signals and determine when the negative of the input
pattern has been suitably stored in the storage arrays.
With only switch 1 on, this same information will be

printed and also the SF, SS, and DE arrays will be printed after each iteration. With switches 1 and 2 on, all the previous information will be printed, and a punch of the SF and SS arrays will be made after each iteration. Therefore, switch 2 will be turned on when it is determined that a pattern has been suitably stored, and a punch of this stored pattern will be made and filed for future use. If switch 3 is turned on, the computer will leave the basic iteration and await new input data. This provides an exit from the program in case the printed output data are uninteresting or incorrect and it is desired to begin storage or comparison of a different pattern.

In this chapter the Model PR-9, patterned after the human visual system, was derived, a flow diagram for the computer simulation was described, and the Fortran program for the computer simulation was explained. The next step in this investigation will be to derive various patterns, store them in the model, and then test the model for recognition of these patterns after they have undergone variations. This step is discussed in the next chapter.

GE/EE/63-11

V. Testing Procedures

After the model of area 17 was developed and a
computer program completed, it was necessary to derive
several sets of patterns to use in testing the pattern
invariance recognition capabilities of the model. It
was decided to begin with a very simple bar pattern and
proceed to more complex patterns.

The first pattern set is shown in Figs. 6, 7, and 8.
An X in the pattern represents a signal of 50 units and
a blank indicates a signal of zero units. The basic
procedure followed was to store pattern #1-A in the SF
and SS arrays until the sum of the squares of the error
signals, UU, approached a minimum, then obtain a punched
output of the SF and SS arrays. These punched arrays of
pattern #1-A were now read back into the storage arrays,
with pattern #2-A used as the input pattern. The computer
was now run through several iterations and the typed out-
put of UU used as an indication of the degree of recog-
nition of pattern #2-A. This comparison procedure was
repeated for each of the remaining patterns in set "A".
The data obtained from these runs are on pages 83-92
in Appendix C.

The coupling constants G, H, and P permit varying
the coupling between cells in the horizontal or vertical
direction. The constants D and DD permit varying the
overall coupling from the SF and SS arrays respectively.

35
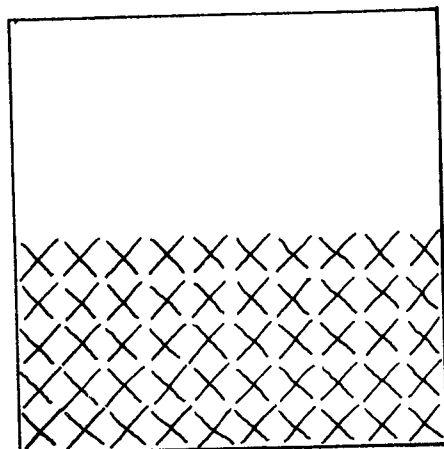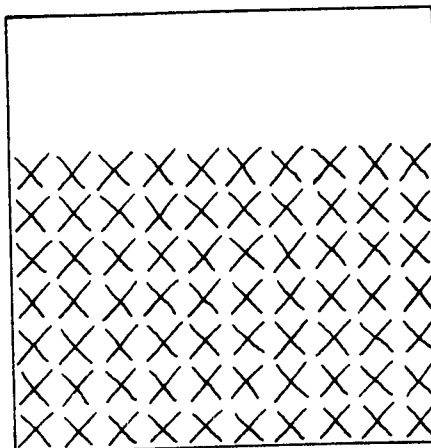
PATTERN #1-A

PATTERN #2-A
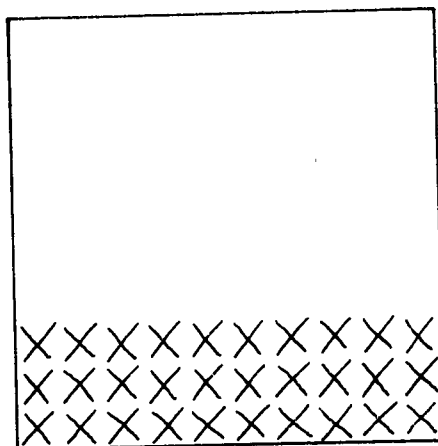
PATTERN #3-A

PATTERN #4-A

FIG. 6
PATTERN SET "A". THE NINE PATTERNS IN
THIS SET ARE SHOWN IN THIS FIGURE AND
THE TWO FOLLOWING FIGURES.

PATTERN #5-A
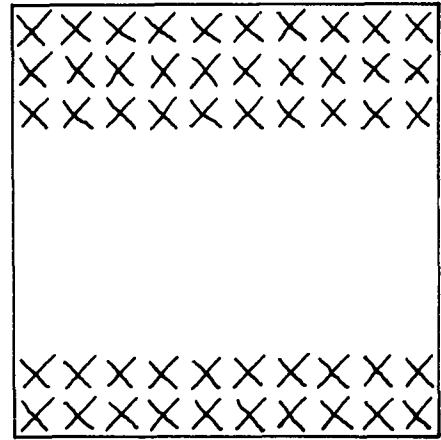
PATTERN #6-A
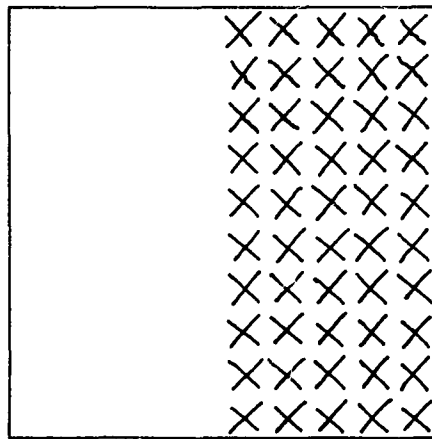
PATTERN #7-A
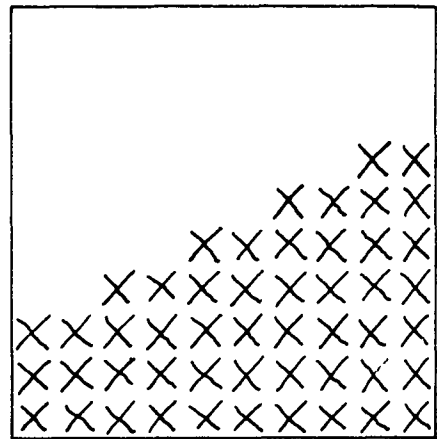
PATTERN #8-A

FIG. 7

PATTERN SET "A"
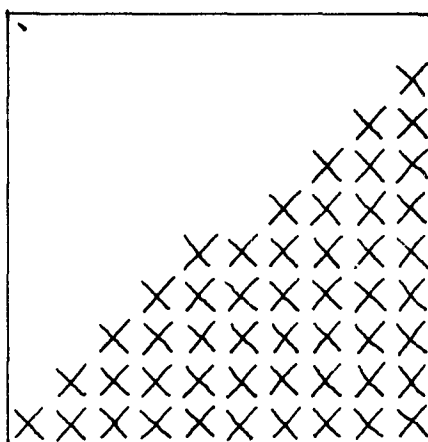
PATTERN # 9-A

FIG. 8

PATTERN SET "A"

The constants A, AA, C, and CC permit varying the rate of storage of the pattern. For all of the testing procedures, the values of C and CC were set at 1.0, A was set at 0.1, and AA was set at 0.01. This permitted a moderate rate of storage in the SF array and a considerably slower rate of storage in the SS array. In the testing with pattern set "A", various types of coupling were used to determine their effects upon the storing of pattern #1-A and upon the recognition of the following patterns in the set.

The four input statements which set the values of the constants determining coupling and rate of storage are called the "metric". The five metrics used in testing the coupling effects are shown in Appendix B. Metric #1 provides equal coupling from each of the four adjacent cells by setting the G, H, and P constants equal to 0.25, and D and DD equal to 1.0. Metric #2 provides stronger vertical coupling than horizontal by setting G1, G3, H1, H3, P1, and P3 equal to 0.5. Metric #3 provides for stronger horizontal than vertical coupling by setting G2, G4, H2, H4, P2, and P4 equal to 0.5. Metric #4 provides no coupling between adjacent cells by setting D, DD, and the G, H, and P constants equal to zero. Metric #5 provides equal coupling, but doubles the coupling over that provided by metric #1 by setting the G, H, and P constants equal to 0.5.

Pattern #1-A was stored using metric #1, metric #2,

and metric #3. Fifteen iterations were required to
store the pattern with metric #1 before the value of
UU reached a minimum (data on pages 83-84 in Appendix C).
Thirteen iterations were required with metric #2, and
twelve iterations with metric #3. Thus, somewhat faster
storage was obtained by using stronger vertical or
horizontal coupling than equal coupling. A punched
output of the stored patterns was obtained for each of
these three metrics. Each of these three stored SF and
SS arrays of pattern #1-A were then compared with
pattern #2-A to determine if the type of coupling used
in the storing procedure affected the recognition
capability. As shown in the data on pages 88-90 in
Appendix C, the metric used in storing pattern #1-A
had little effect upon the recognition of pattern #2-A.
The values of UU on the initial iteration of the compar-
ison were 123121; 121797; and 123477. On the basis of
these results, it was decided to use metric #1 in the
future storing of patterns.

The next step was to make a comparison of all the
patterns in set "A" with the stored pattern #1-A to
determine the degree of recognition of these patterns.
This comparison was made by setting the SF array equal
to zero and feeding the stored SF array of pattern #1-A
into the SS array. This would represent a thoroughly
stored pattern #1-A. In 15 iterations the pattern had
been well stored in the SF array, while the SS array had

barely begun to store the pattern. After a great many
more iterations the pattern would filter through the
SF array and eventually become thoroughly stored in
the SS array, leaving the SF array at zero. This
lengthy process was simulated by feeding the stored
SF array of pattern #1-A into the SS array for the
comparison procedure. This stored pattern #1-A was
then compared with pattern #1-A as the input pattern
and the value of UU on the first iteration taken as the
value representing complete recognition of the input
pattern. All the remaining patterns in set "A" were
then compared with the stored pattern #1-A and the value
of UU obtained on the first iteration used as a measure
of the degree of recognition of the pattern.

Pattern set "B" was then tested on the model. The
patterns in this set are shown in Figs. 9 through 13.
Pattern #1-B was used as the standard pattern. It
was stored in 16 iterations with metric #1. To simulate
thorough storage, the stored SF array of pattern #1-B
was used as the SS array during the comparison of each
of the patterns in set "B" with the standard pattern #1-B.
The SF array was set equal to zero. Metric #1 was used
in the comparison procedures. Four iterations were com-
pleted in the comparison of each pattern in set "B"
with pattern #1-B. These patterns were designed to
simulate vertical displacement and rotation of the bar
in pattern #1-B. The value of UU was used as an indication

41

FIG. 9
PATTERN SET "B". THE 20 PATTERNS IN
THIS SET ARE SHOWN IN THIS FIGURE AND
THE FOUR FOLLOWING FIGURES.
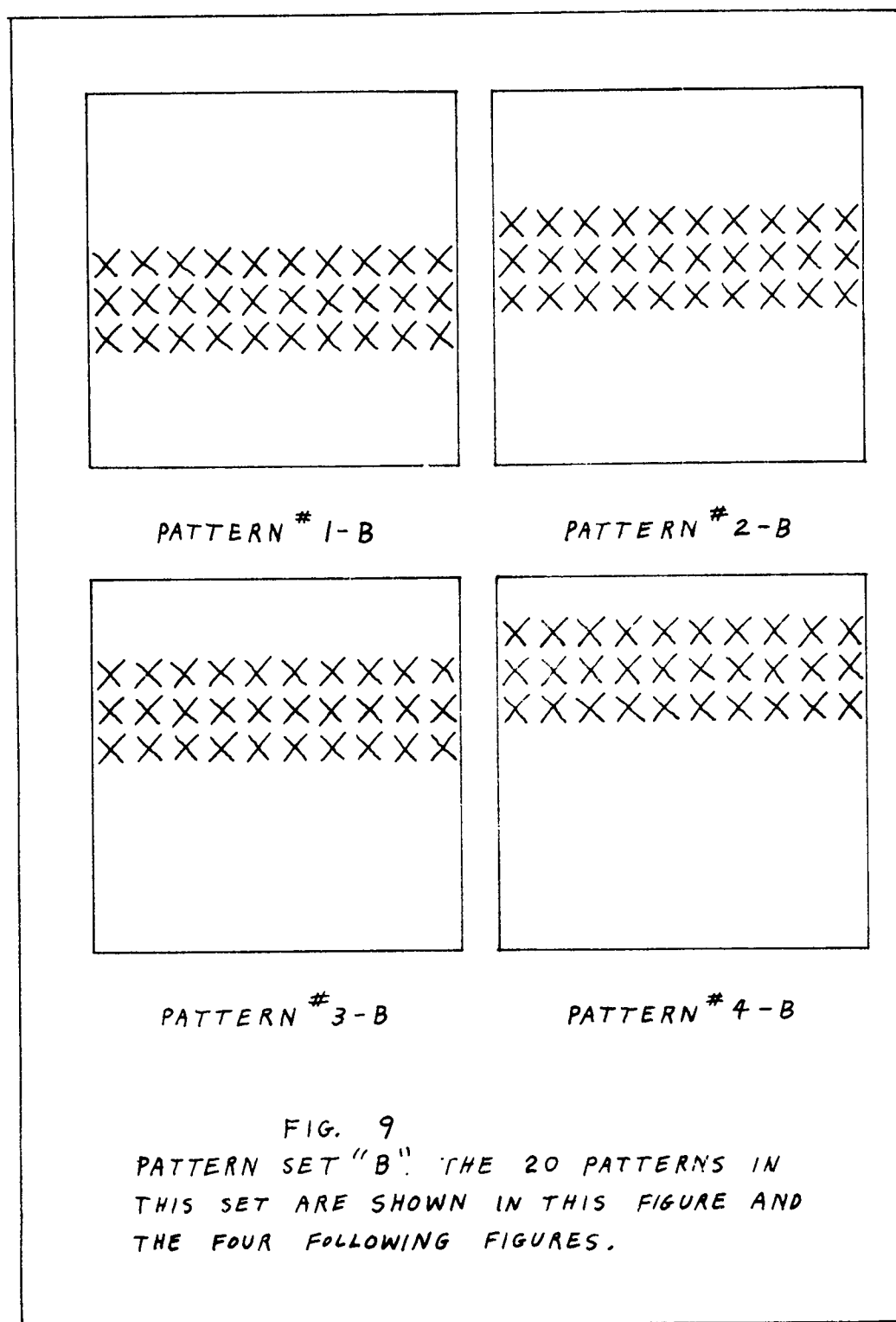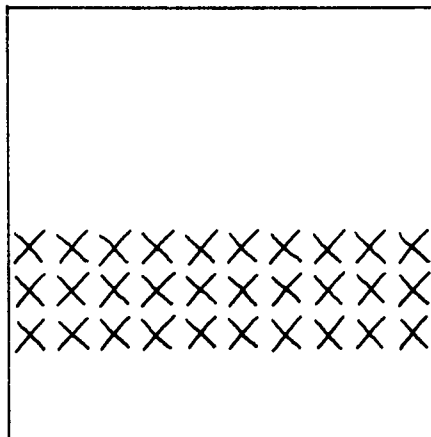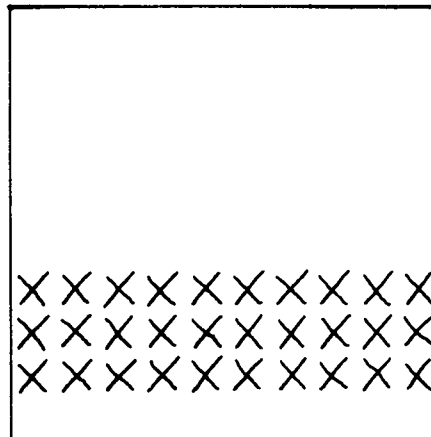
PATTERN # 5-B
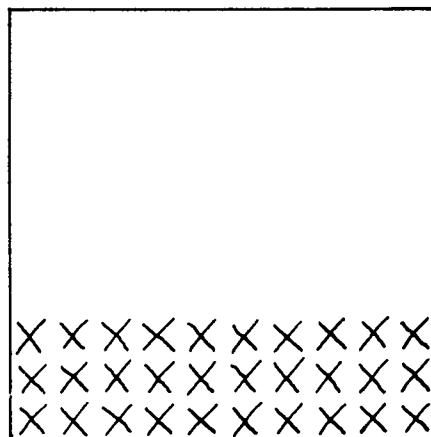
PATTERN # 6-B

PATTERN # 7-B
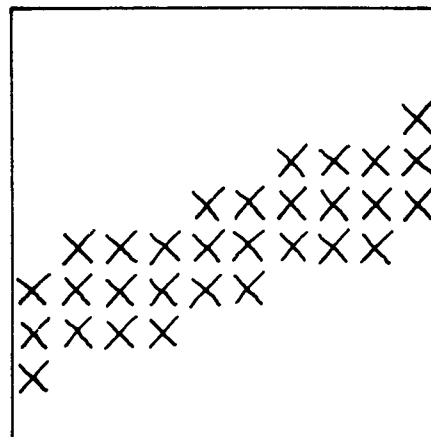
PATTERN # 8-B

FIG. 10

PATTERN SET "B"
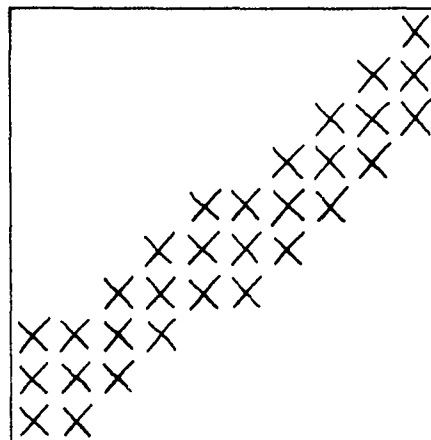
PATTERN # 9-B
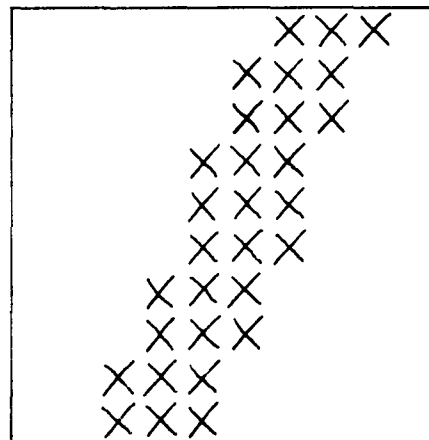
PATTERN # 10-B
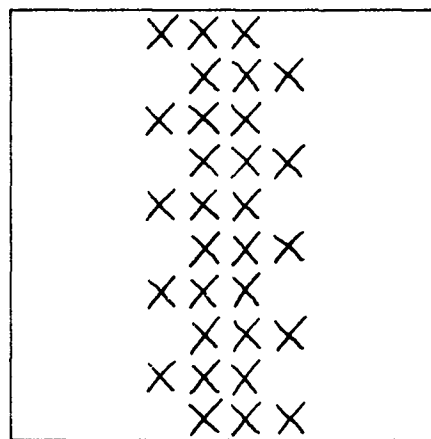
PATTERN # 11-B
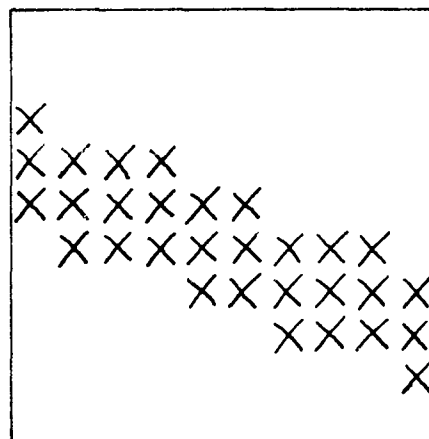
PATTERN # 12-B

FIG. 11

PATTERN SET "B"
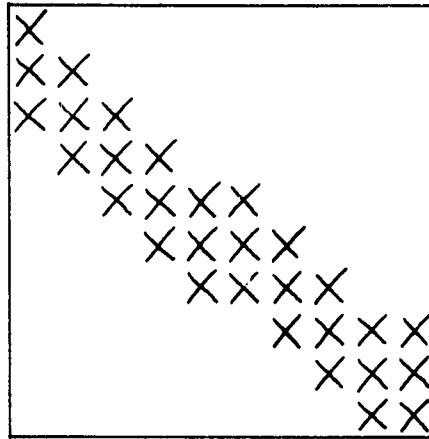
PATTERN # 13-B
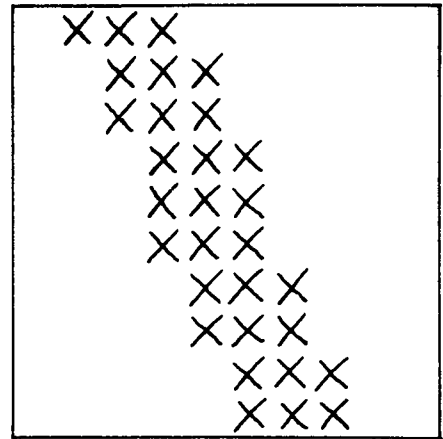
PATTERN # 14-B
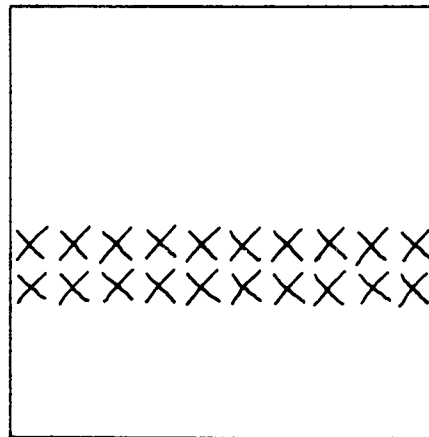
PATTERN # 15-B
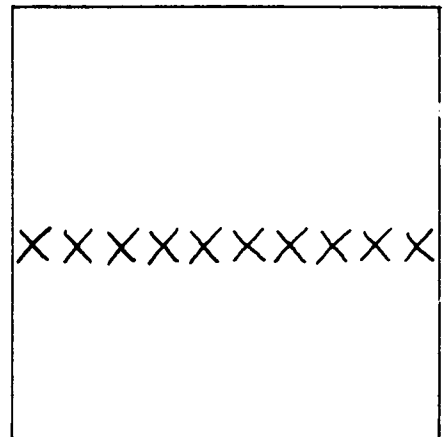
PATTERN # 16-B

FIG. 12

PATTERN SET "B"
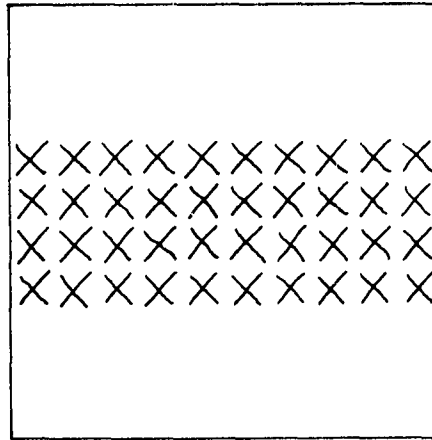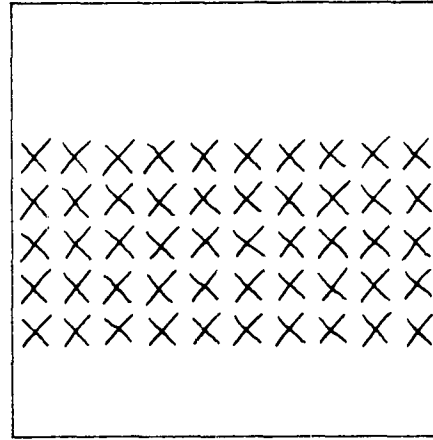
PATTERN #17-B   PATTERN #18-B
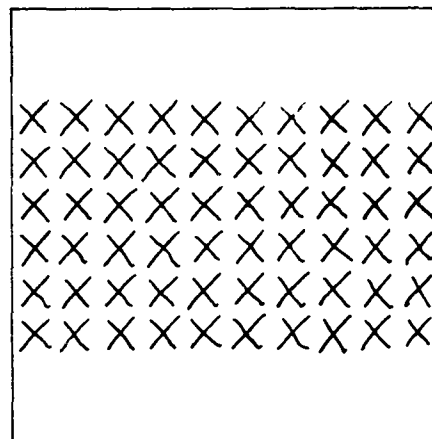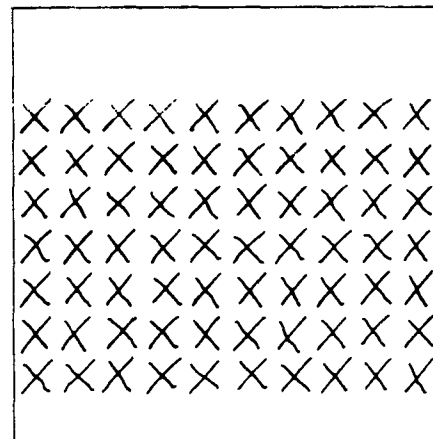
PATTERN #19-B   PATTERN #20-B

FIG. 13

PATTERN SET "B"

of the degree of recognition of the patterns.

Pattern set "C" (Figs. 14 through 19) was designed to test the model for recognition of a pattern when displaced vertically, horizontally, or diagonally, and when varied in size and shape. The metric used in the comparison of the vertically displaced patterns was varied to determine if one type of coupling provided better recognition capabilities than another. Pattern 1-C was stored in 16 iterations with metric $^\#1$. The remaining patterns were then compared through two iterations each with stored pattern $^\#1$-C using metric $^\#1$. Then patterns $^\#2$-C, $^\#3$-C, and $^\#4$-C, and $^\#5$-C were again compared with pattern $^\#1$-C using metric $^\#2$, metric $^\#3$, metric $^\#4$, and metric $^\#5$. This provided data for determining if one metric provided better pattern invariance recognition than the others.

Pattern set "D" (Figs. 20 through 24) was designed to test the model for its ability to distinguish variations of a certain stored letter from other letters of the alphabet. A standard letter "A" was stored and then compared with several variations of the letter "A" and other letters of the alphabet.

This completed the testing of the model in this paper for its pattern invariance recognition capabilities. Four sets of patterns were used in these testing procedures. The basic procedure was to store the first pattern of each set, then compare the remaining patterns with the stored
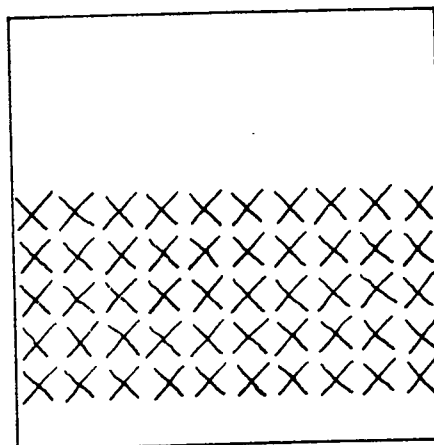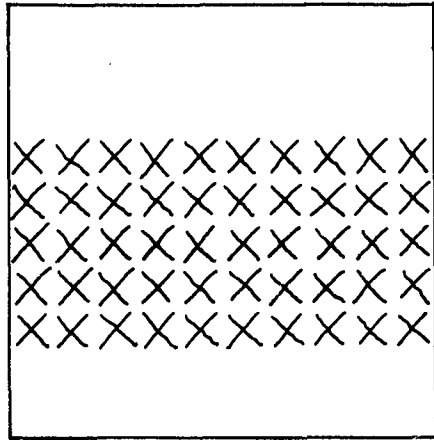
PATTERN #1-C

PATTERN #2-C

PATTERN #3-C

PATTERN #4-C

FIG. 14
PATTERN SET "C". THE 24 PATTERNS IN
THIS SET ARE SHOWN IN THIS FIGURE AND
THE FIVE FOLLOWING FIGURES
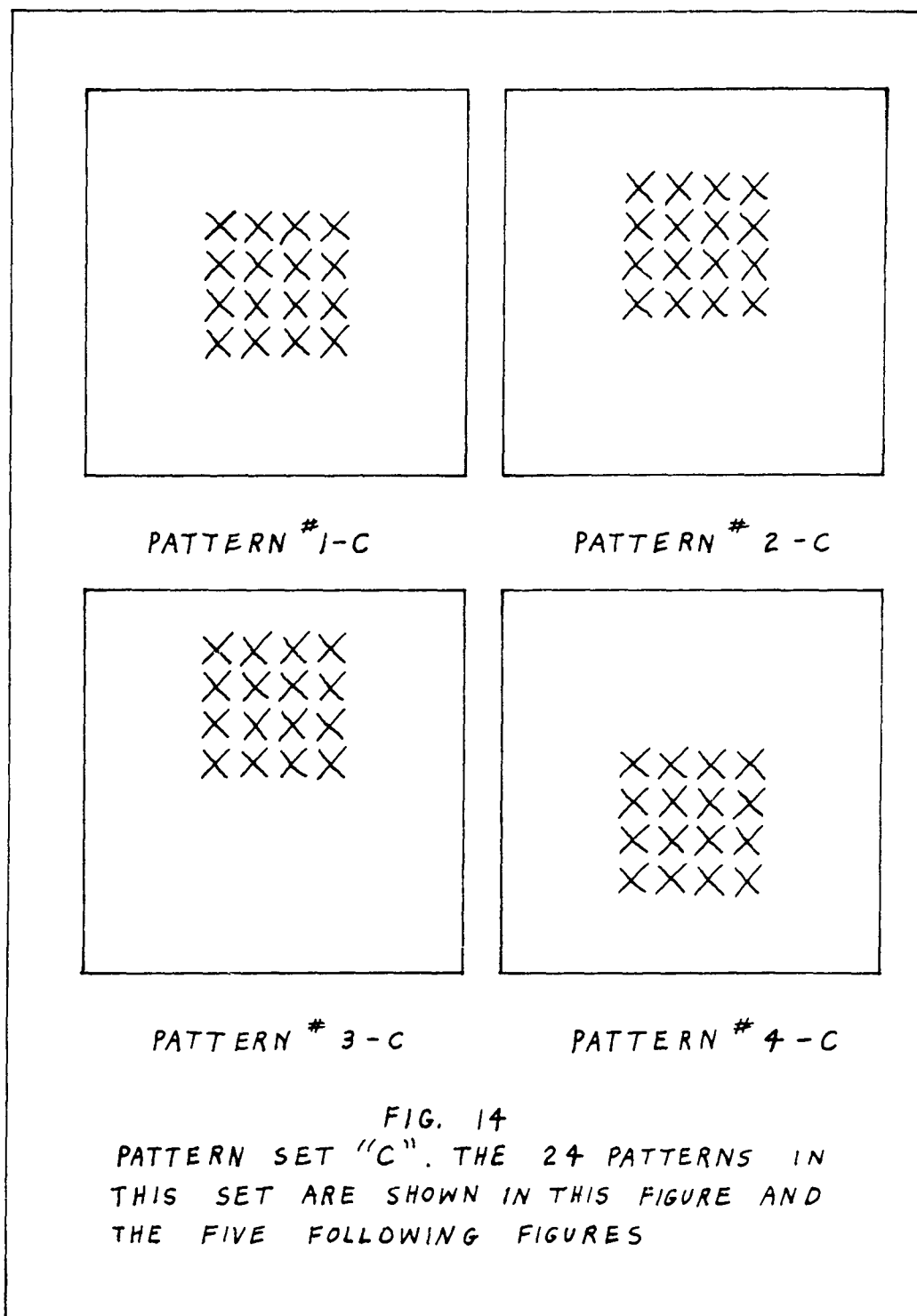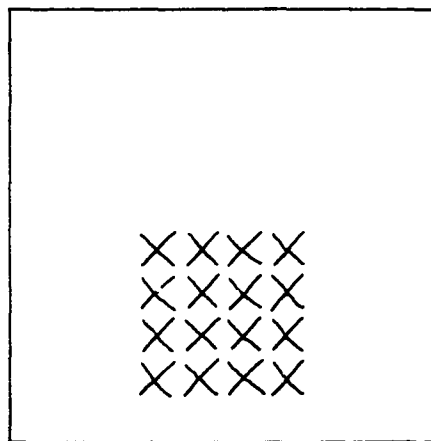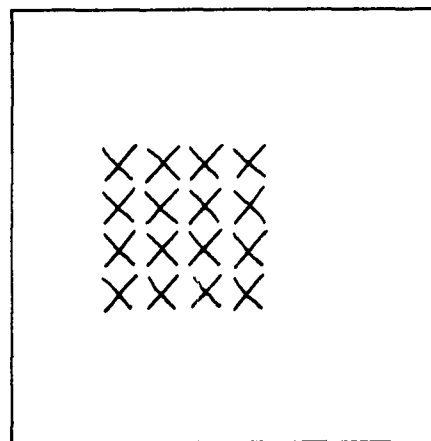
PATTERN #5-C
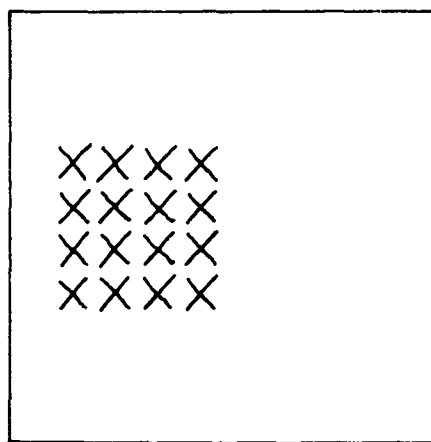
PATTERN #6-C

PATTERN #7-C
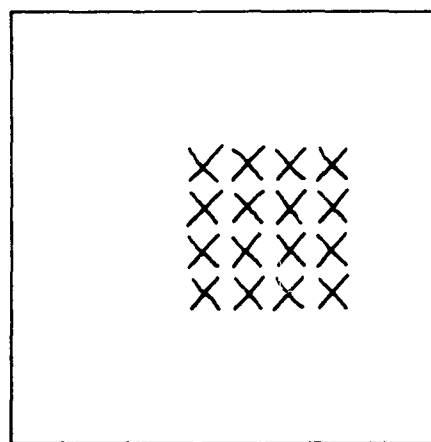
PATTERN #8-C

FIG. 15

PATTERN SET "C"

PATTERN #9-C

PATTERN #10-C

PATTERN #11-C

PATTERN #12-C

FIG. 16
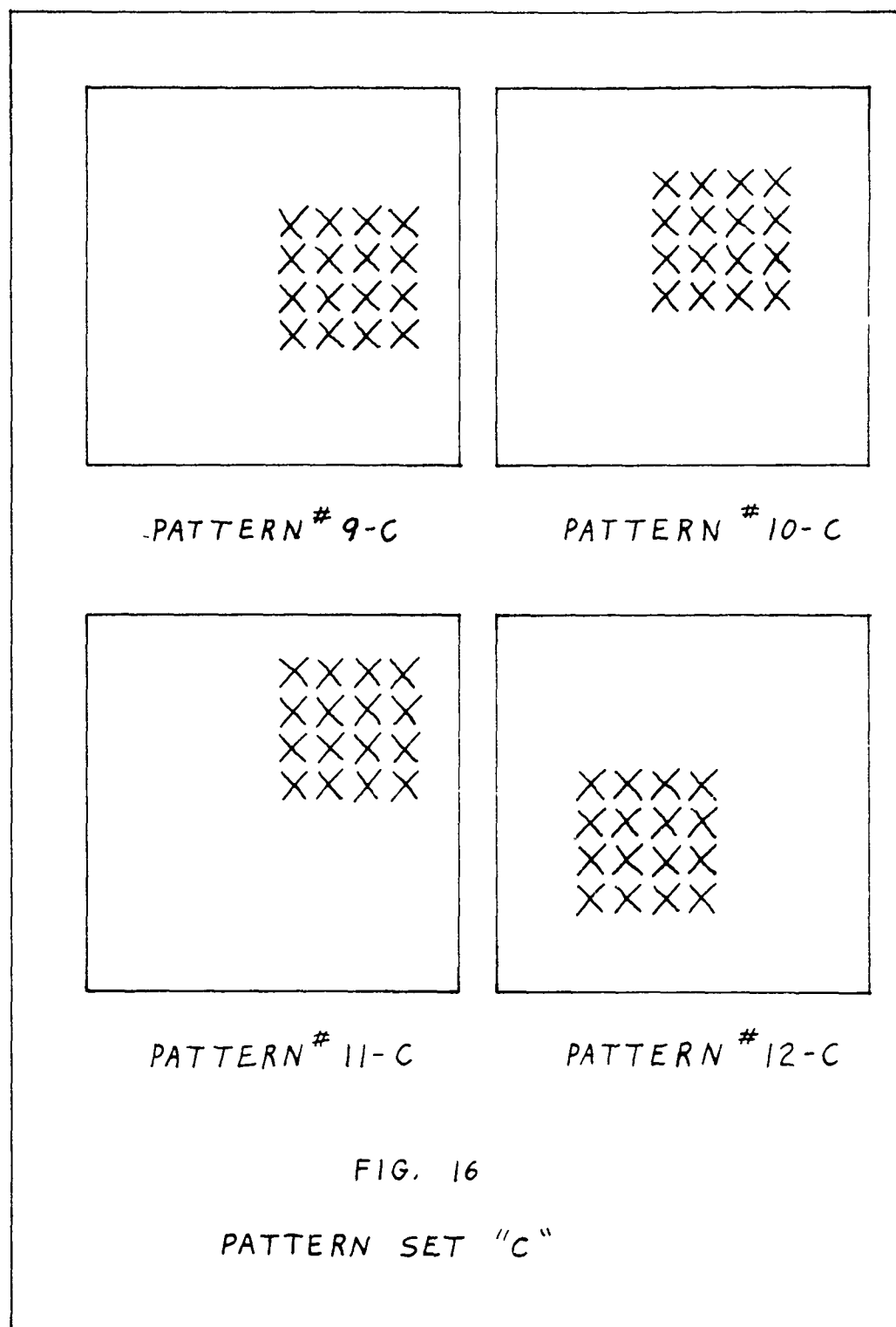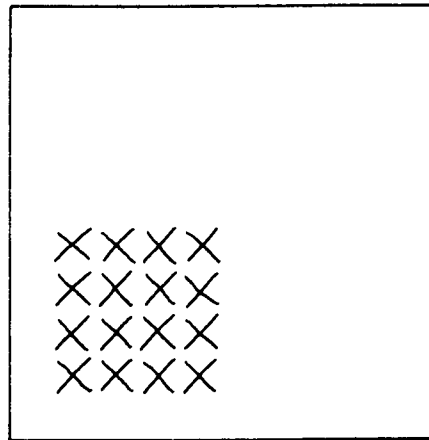
PATTERN SET "C"
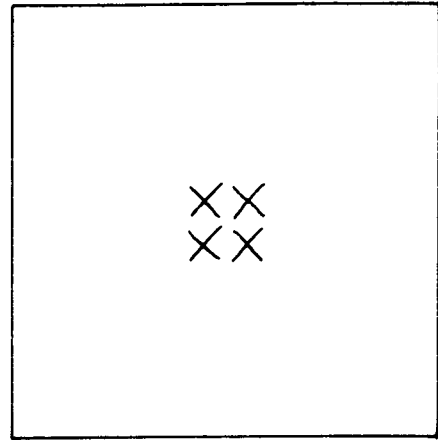
PATTERN # 13-C   PATTERN # 14-C
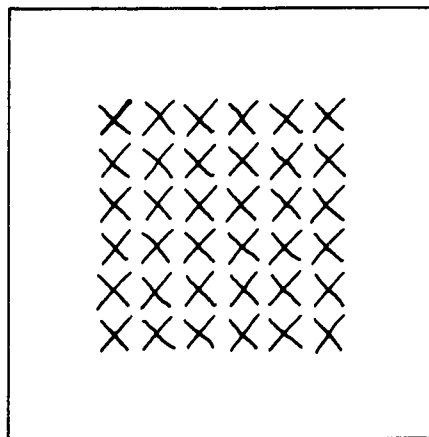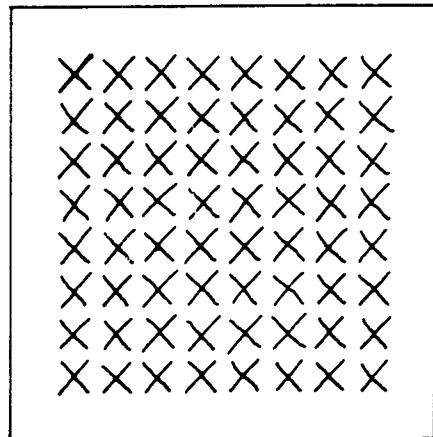
PATTERN # 15-C   PATTERN # 16-C

FIG. 17

PATTERN SET "C"

GE/EE/63-11
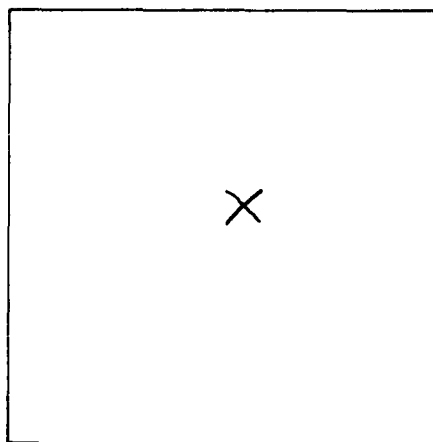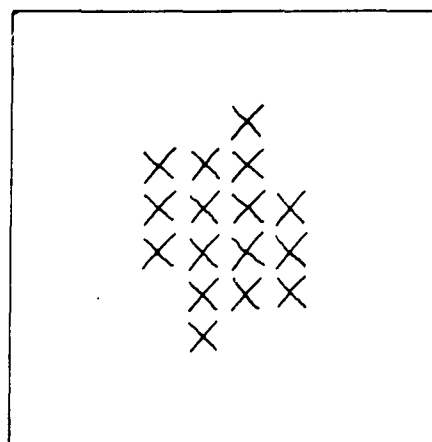
PATTERN # 17-C   PATTERN # 18-C
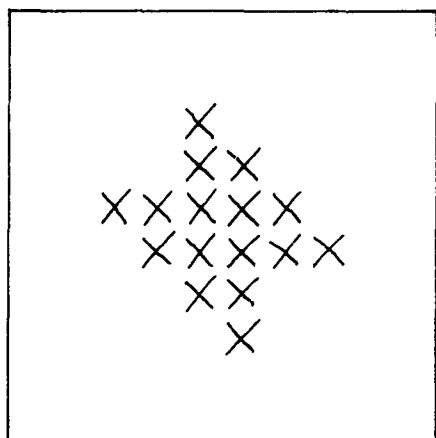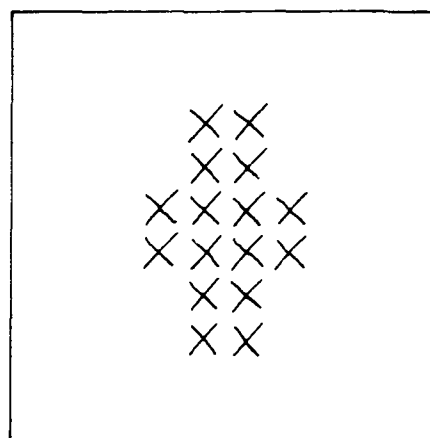
PATTERN # 19-C   PATTERN # 20-C

FIG. 18

PATTERN SET "C"
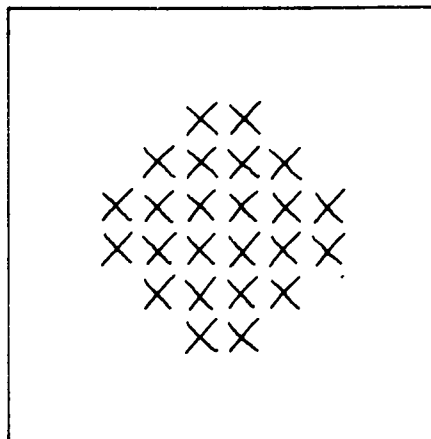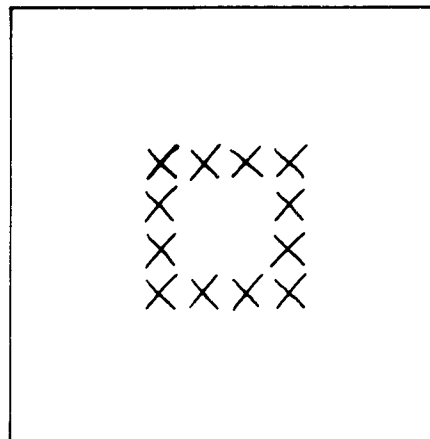
PATTERN # 21-C   PATTERN # 22-C
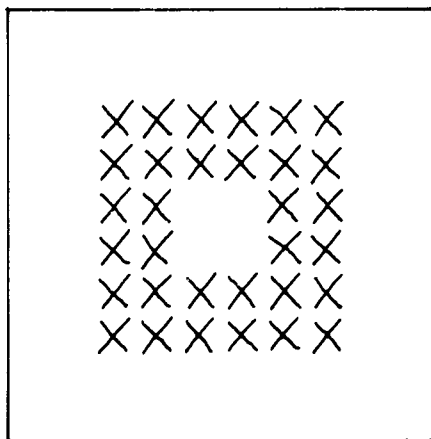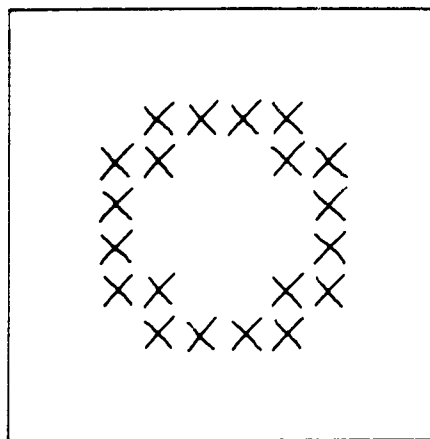
PATTERN # 23-C   PATTERN # 24-C

FIG. 19

PATTERN SET "C"
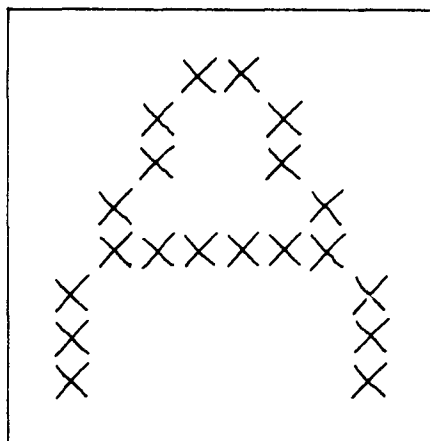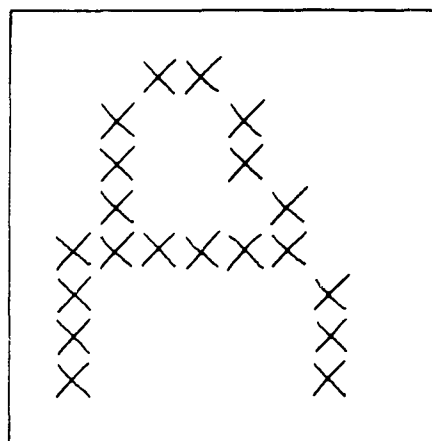
PATTERN #1-D   PATTERN #2-D
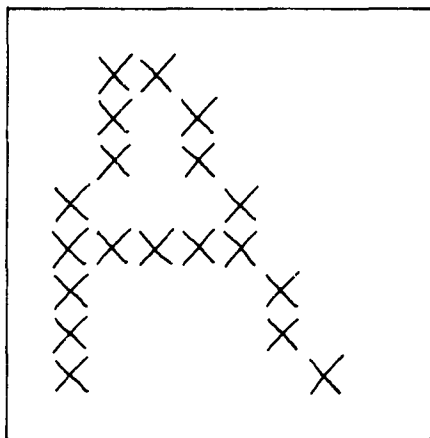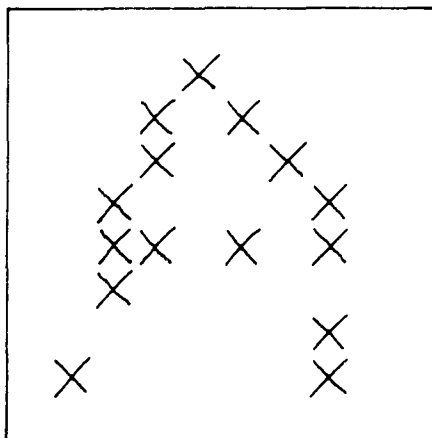
PATTERN #3-D   PATTERN #4-D

FIG. 20
PATTERN SET "D". THE 17 PATTERNS IN
THIS SET ARE SHOWN IN THIS FIGURE
AND THE FOUR FOLLOWING FIGURES.
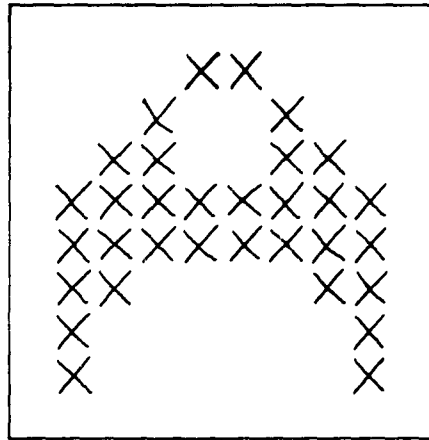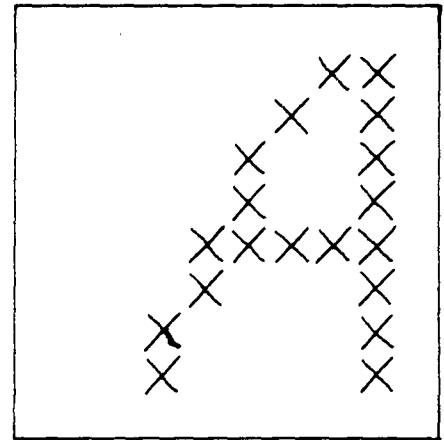
PATTERN #5-D   PATTERN #6-D
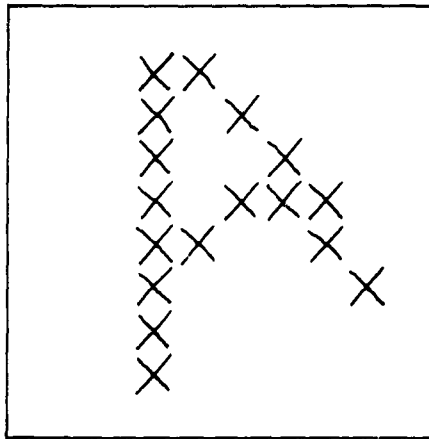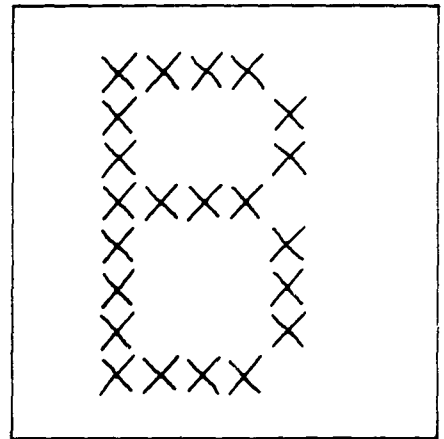
PATTERN #7-D   PATTERN #8-D

FIG. 21

PATTERN SET "D"
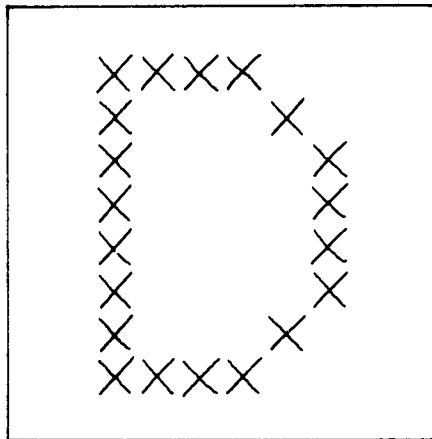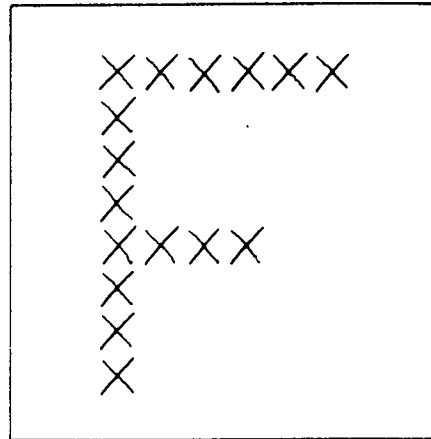
PATTERN # 9-D   PATTERN # 10-D
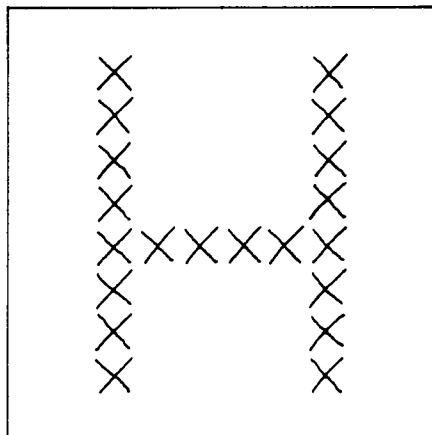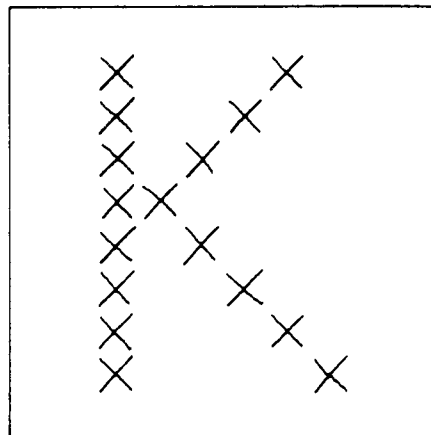
PATTERN # 11-D   PATTERN # 12-D

FIG. 22

PATTERN SET "D"
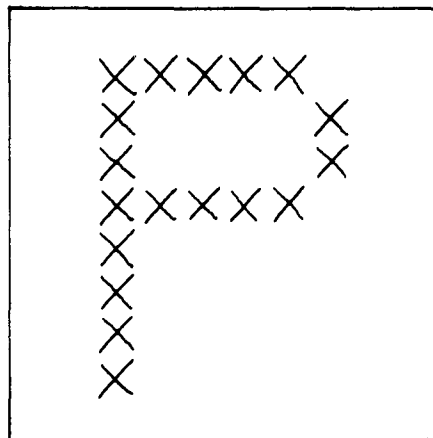
PATTERN # 13-D
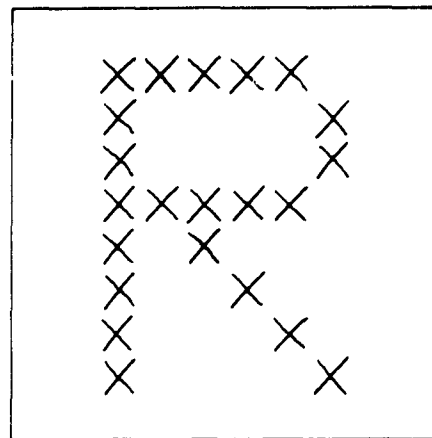
PATTERN # 14-D
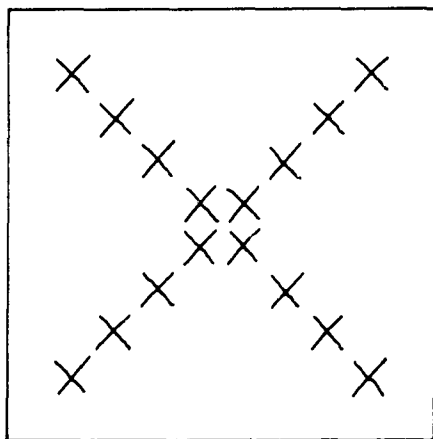
PATTERN # 15-D
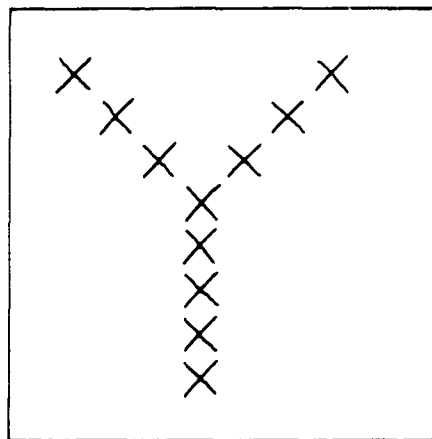
PATTERN # 16-D

FIG. 23

PATTERN SET "D"
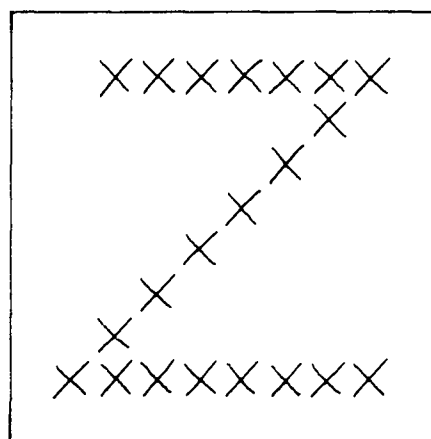
PATTERN # 17-D

FIG. 24

PATTERN SET "D"

pattern. The pattern sets were designed to test the model for recognition of a pattern after it was translated, rotated, or varied in size and shape. The results of these tests and the conclusions drawn from them will be discussed in the next chapter.

VI. <u>Results</u> <u>and</u> <u>Conclusions</u>

The data obtained from testing model Pr-9 with
pattern sets A, B, C, and D were evaluated by plotting
line graphs of UU versus the amount of pattern variation.
This produced graphs of the sensitivity of the model to
translation, rotation, size variation, and shape variation.

Pattern #1-A is a simple horizontal bar with a width
of five cells. The data obtained from testing the model
with pattern set "A" (pages 90-92 of Appendix C) were
used to obtain sensitivity curves for rotation and
vertical displacement of this horizontal bar. These
curves are shown in Fig. 25 and Fig. 26. The minimum
point on these curves is the value of UU obtained by
comparing the stored pattern #1-A with the same pattern
as the input pattern. This point indicates complete
recognition and points above this indicate a lesser
degree of recognition. The lowering of the curve by
sucessive iterations indicates a learning of the new
patterns. For this bar pattern, a rotation of about
30 degees gave the same degree of recognition as a
vertical displacement of one cell width (UU = 50,000).

The data from pattern set "B" (pages 94-99 of
Appendix C) provided sensitivity curves for rotation,
vertical displacement, and size variation. These
curves are shown in Figs. 27, 28, and 29. Again, 30
degrees of rotation and one cell width of vertical

GE/EE/63-11

U_U/-I0³

250

200

150

100

50
40

PATTERN #1-A

PATTERN #4-A

PATTERN #5-A

ITERATION #1

ITERATION #2

-2   -1   0   1   2

VERTICAL DISPLACEMENT
(NO. OF CELLS)
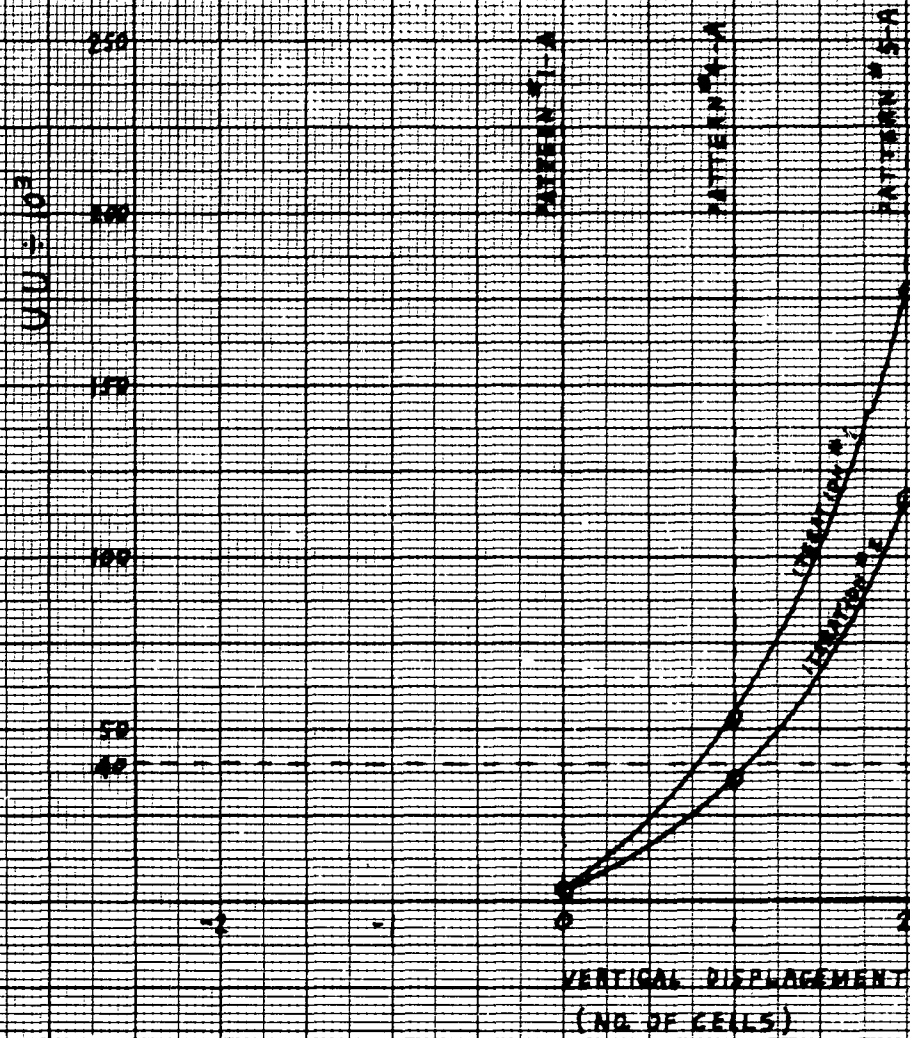
FIG. 2 5

SENSITIVITY OF MODEL PR-9 TO VERTICAL DISPLACEMENT
OF PATTERN #1-A

61

K·E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO   MADE IN U S A
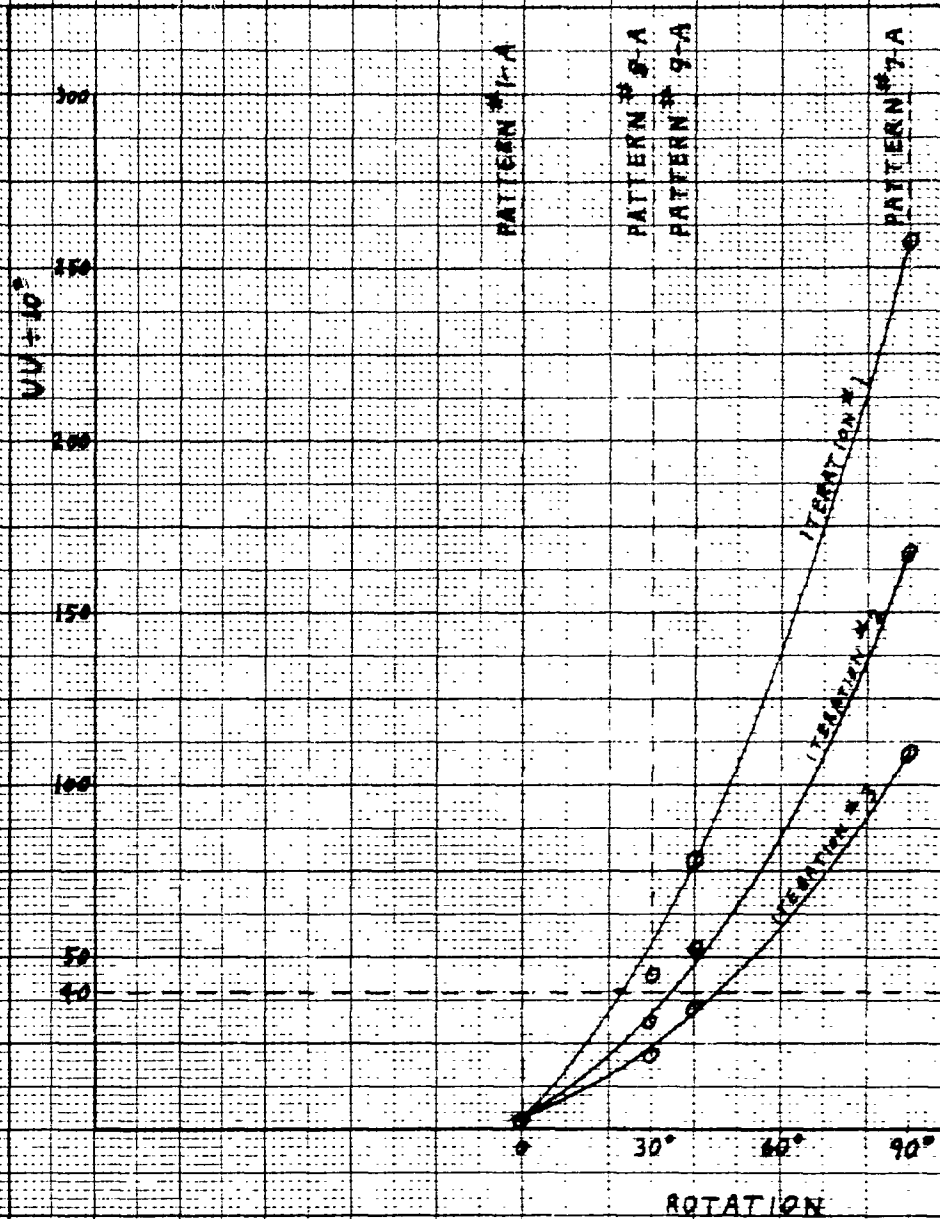
FIG. 26

SENSITIVITY OF MODEL PR-9 TO ROTATION
OF PATTERN # 1-A

displacement produced the same degree of recognition, although the value of UU was about 85,000 rather than 50,000. This indicated slightly better recognition of variations in pattern $#$1-A than in pattern $#$1-B. This could have been due to pattern $#$1-A being located on the edge cells at the bottom of the array. This edge cell effect also seems to produce a difference in the value of UU for the vertical displacement of pattern $#$1-B. When the pattern is displaced three cell widths down, it lies on the lower edge cells, producing a lower value for UU than an equal displacement in the opposite direction. The graph of sensitivity to size variation in Fig. 29 indicates a better recognition of pattern $#$1-B when decreased in size than when increased in size.

Pattern set "C" was designed to eliminate any edge cell effects by keeping the pattern off the perimeter of the array. The data from this set (pages 99-107 of Appendix C) provided sensitivity curves for vertical displacement, horizontal displacement, diagonal displacement, size variation, and shape variation (Figs. 30 through 34). The metric used during the pattern comparison was varied to obtain a sensitivity curve for vertical displacement for each of the five metrics (Fig. 35). The sensitivity curves for horizontal and vertical displacement were identical. The value of UU for a displacement of one cell width was 37000, which was less than the value for an equal displacement of pattern
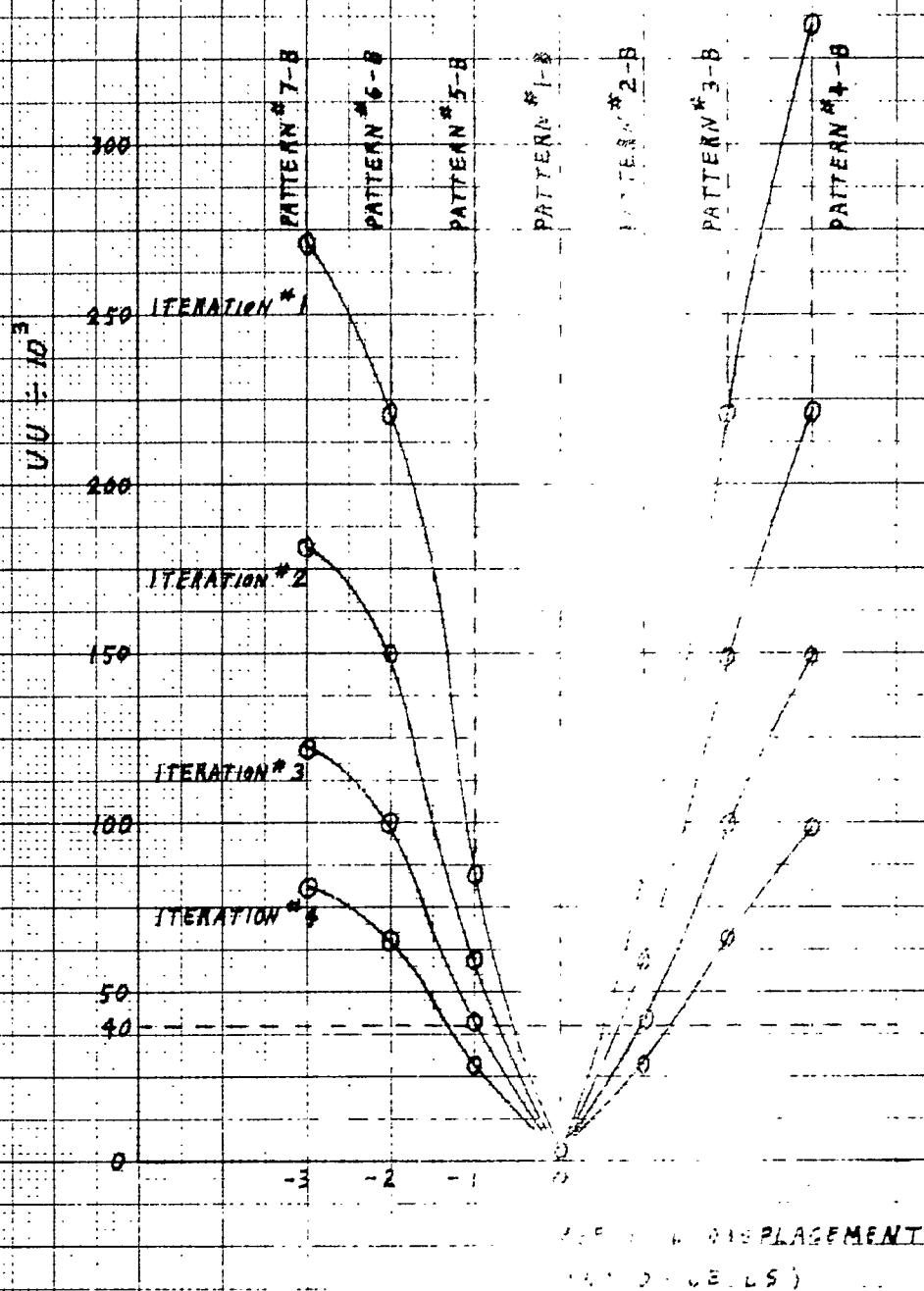
63

$U.U. \div 10^3$

PATTERN #7-B
PATTERN #6-B
PATTERN #5-B
PATTERN #1-B
PATTERN #2-B
PATTERN #3-B
PATTERN #4-B

300

250 — ITERATION #1

200

ITERATION #2

150

ITERATION #3

100

ITERATION #4

50
40

0

-3   -2   -1   0

DISPLACEMENT
(IN DECELS)

FIG. 27

SENSITIVITY OF MODEL TO VERTICAL

DISPLACEMENT OF PATTERNS #1-B

FIG. 2B

SENSITIVITY OF MODEL PR-9 TO ROTATION OF
PATTERN #1-B

FIG. 24
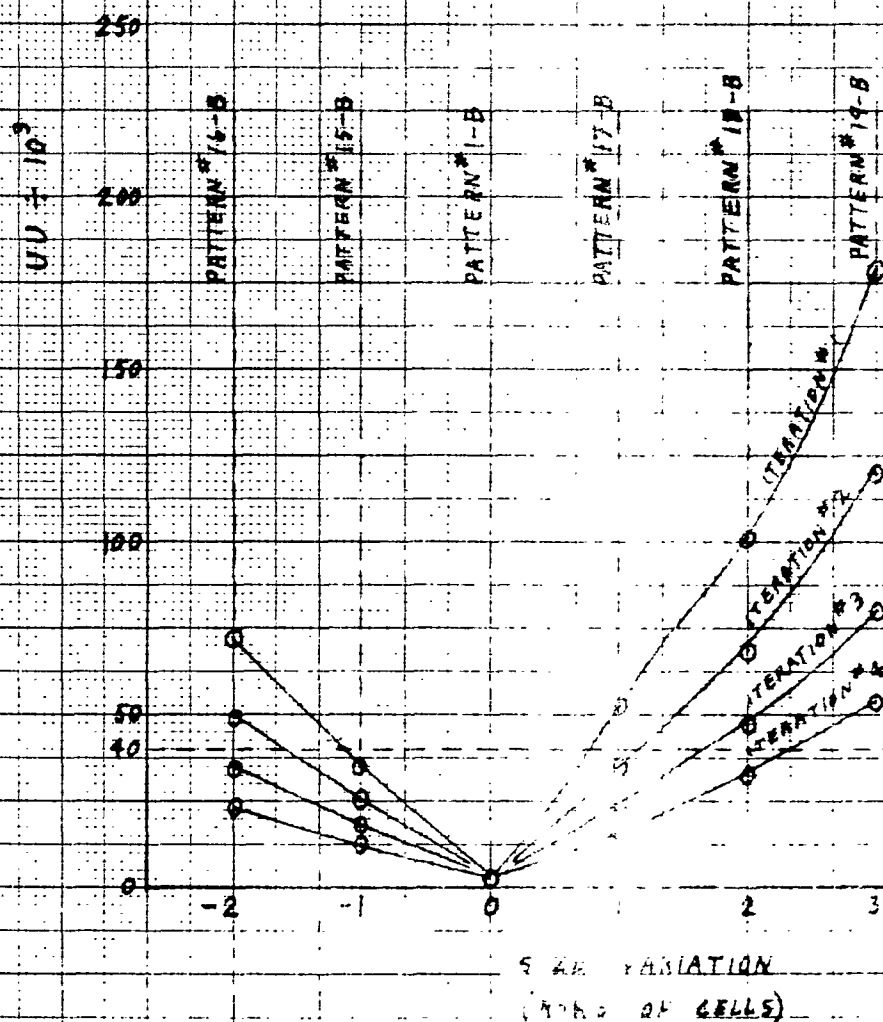
SENSITIVITY OF MODEL FOR VARIATIONS IN SIZE OF PATTERN #1-B

GE/EE/63-11

#1-B. Diagonal displacement produced larger values of UU than horizontal or vertical displacement. The recognition for a decrease in size was better than for an increase in size, as it was in pattern set "B". In Fig. 34 is shown the sensitivity to variations in shape. The values of UU were comparatively low for patterns #18-C through #22-C, but they increased greatly for patterns #23-C and #24-C. In Fig. 35 is shown the effect upon the sensitivity of varying the metric. Metric #4 provided considerably better recognition capability than any of the other metrics. For this reason, metric #4 was used in the comparison procedures for set "D".

In pattern set "D", the letter "A" was stored and then compared with several variations of the letter "A" and with various other letters of the alphabet. The results are shown in Fig. 36 (data on pages 107-110 in Appendix C). Patterns #2-D through #7-D are variations of the letter "A", and patterns #8-D through #17-D are the various other letters. There was generally better recognition of variations of the letter "A" than of the other letters, however, this difference does not seem great enough to be of significance when compared to the capability of the visual system in distinguishing between these same patterns.

All of these results indicate that the model of area 17 is capable of pattern invariance recognition to some degree. If the minimum value of UU in the sensitivity

GE/EE/63-11

$UU \div 10^3$

PATTERN #5-C
PATTERN #4-C
PATTERN #1-C
PATTERN #2-C
PATTERN #3-C

ITERATION #1
ITERATION #2

200

150

100

50
40

0

-2   -1   0   1   2

VERTICAL DISPLACEMENT
(NO. OF CELLS)

FIG. 30

SENSITIVITY OF MODEL FR-9 TO VERTICAL
DISPLACEMENT OF PATTERN #1-C

$\Sigma \Sigma = 10^3$

200

150

PATTERN #7-C

PATTERN #6-C

PATTERN #1-C

PATTERN #8-C

PATTERN #9-C

100

50

40

0

-2 -1 0 1 2

HORIZONTAL DISPLACEMENT

(NO. OF CELLS)

FIG. 31

SENSITIVITY OF MODEL PR-9 TO HORIZONTAL

DISPLACEMENT OF PATTERN #1-C
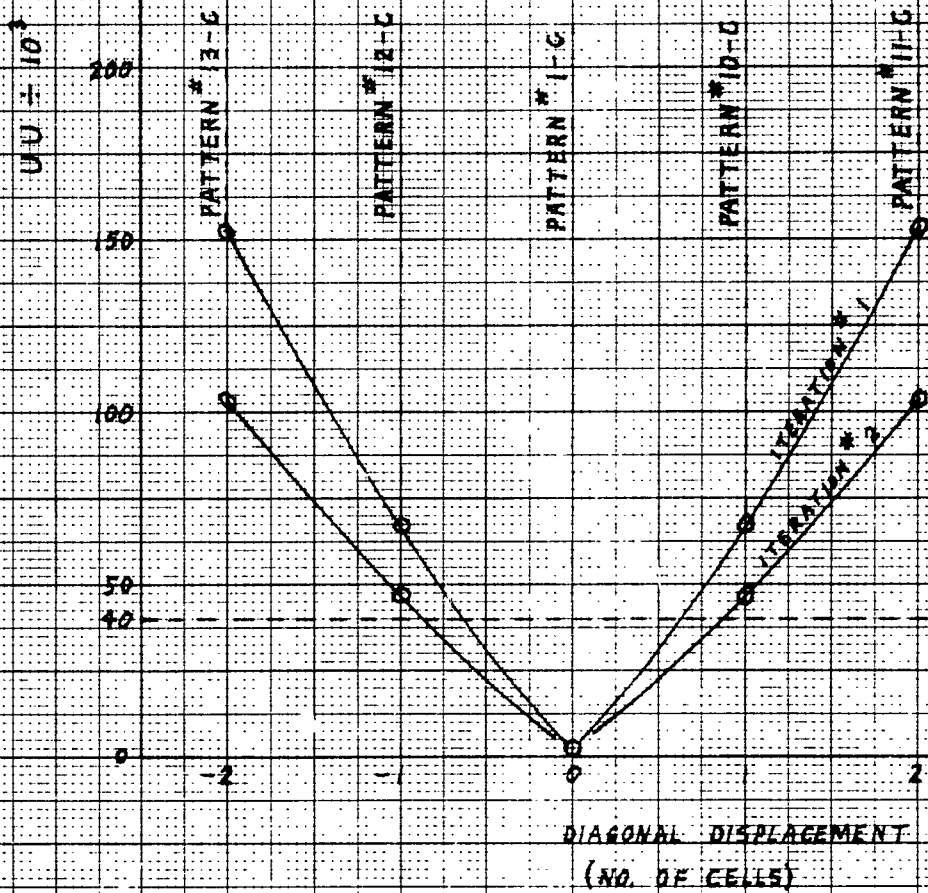
FIG. 32

SENSITIVITY OF MODEL PR-9 TO DIAGONAL
DISPLACEMENT OF PATTERN #1-G

GE/EE/63-11

$UV = 10^{-3}$

PATTERN #17-C

PATTERN #14-C

PATTERN # 1-C

PATTERN # 15-C

PATTERN #16-C

ITERATION #1

ITERATION #2

SIZE VARIATION

FIG. 33

SENSITIVITY OF PR-9 TO VARIATIONS IN
SIZE OF PATTERN #1-C

71
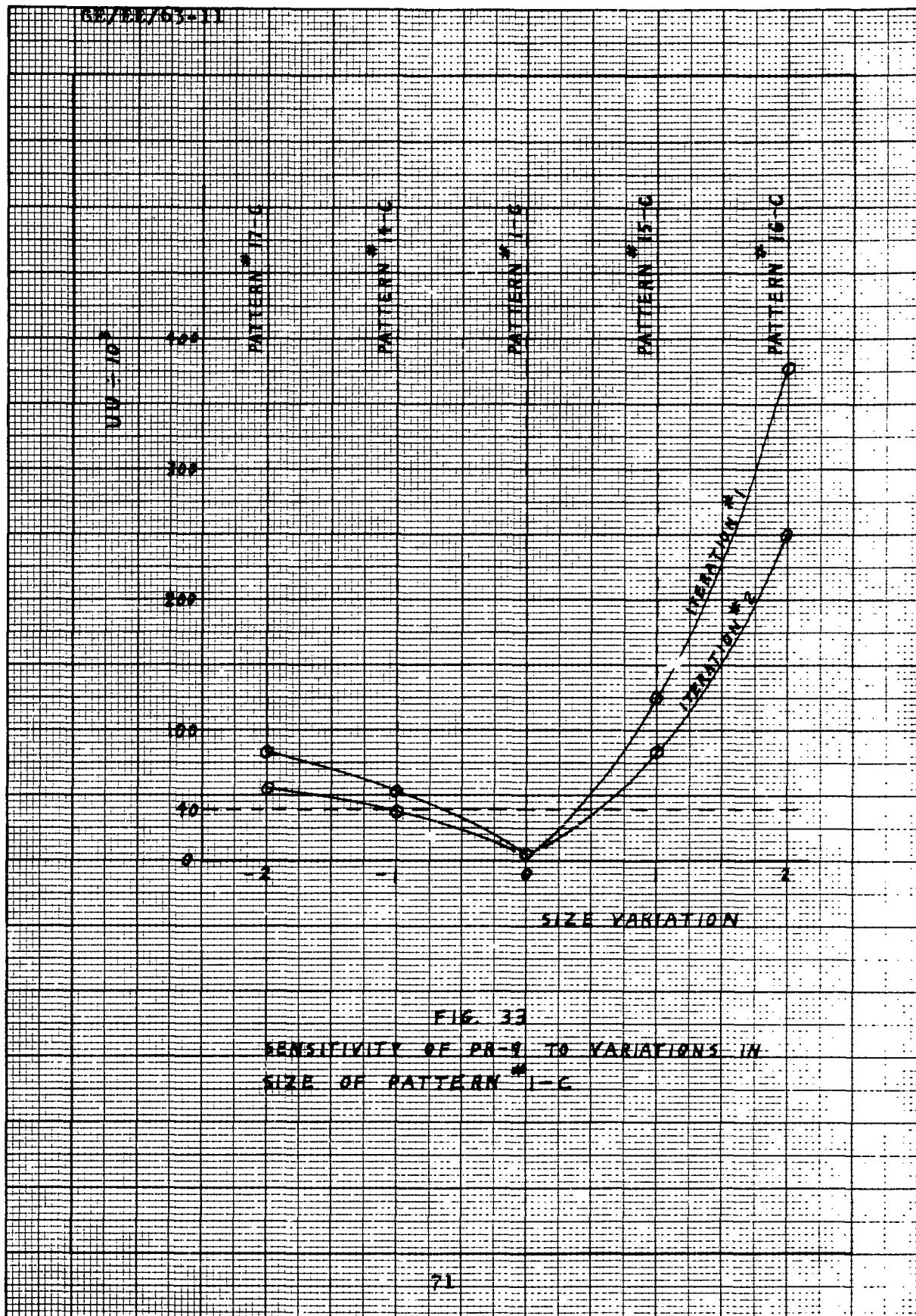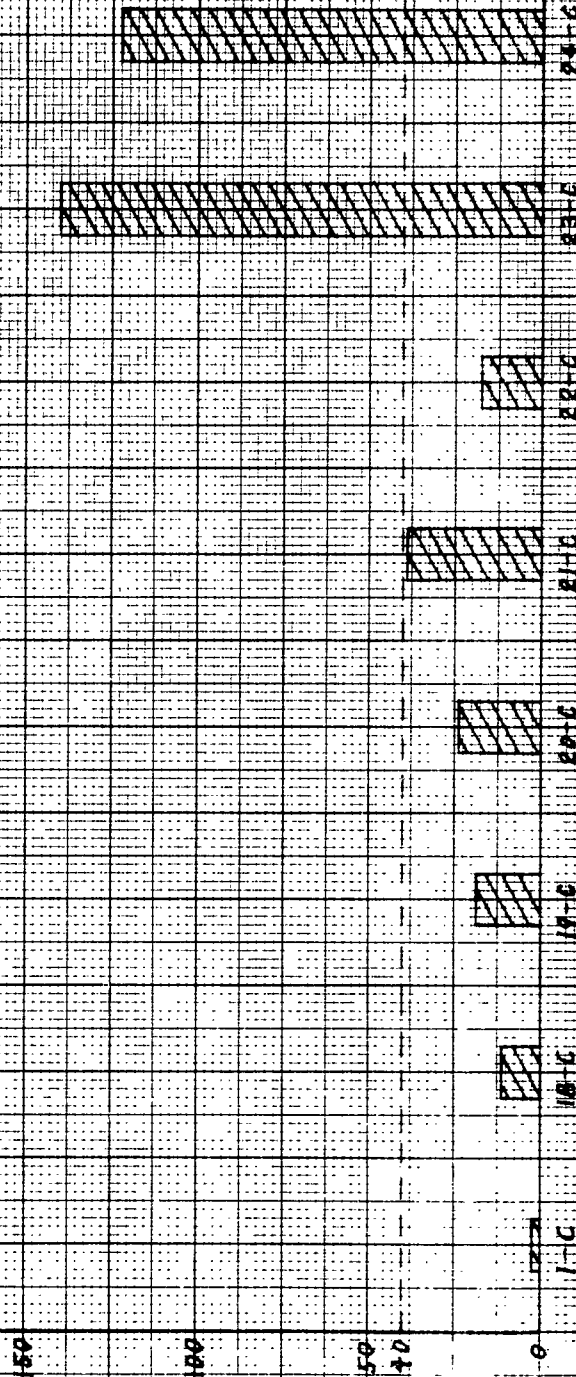
FIG. 34 SENSITIVITY OF MODEL PR-9 TO VARIATIONS IN THE SHAPE OF PATTERN #1-C

72
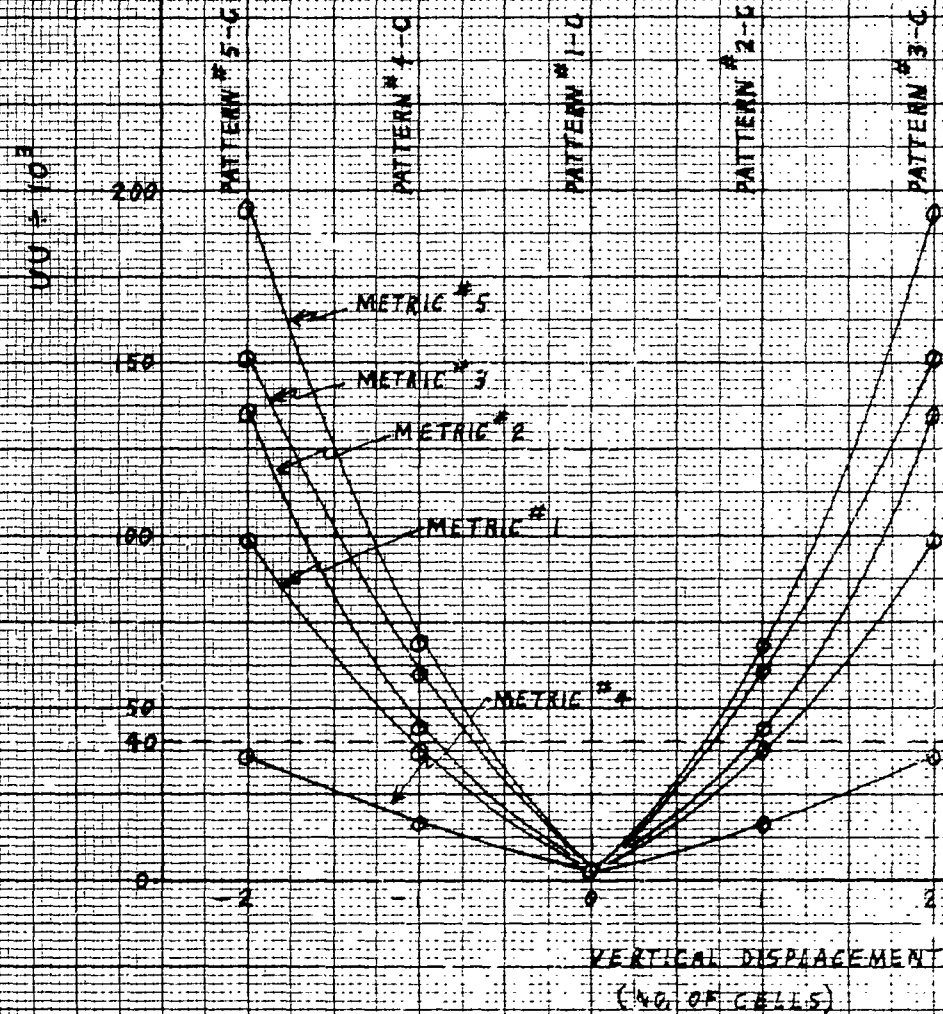
FIG 3 5

THIS GRAPH SHOWS THE EFFECTS OF VARYING
THE CELL COUPLING UPON THE SENSITIVITY
OF MODEL PR-9 TO VERTICAL DISPLACEMENT
OF PATTERN #1-C

FIG. 36

GRAPH SHOWING THE DEGREE OF RECOGNITION OF THE PATTERNS IN PATTERN SET "D"
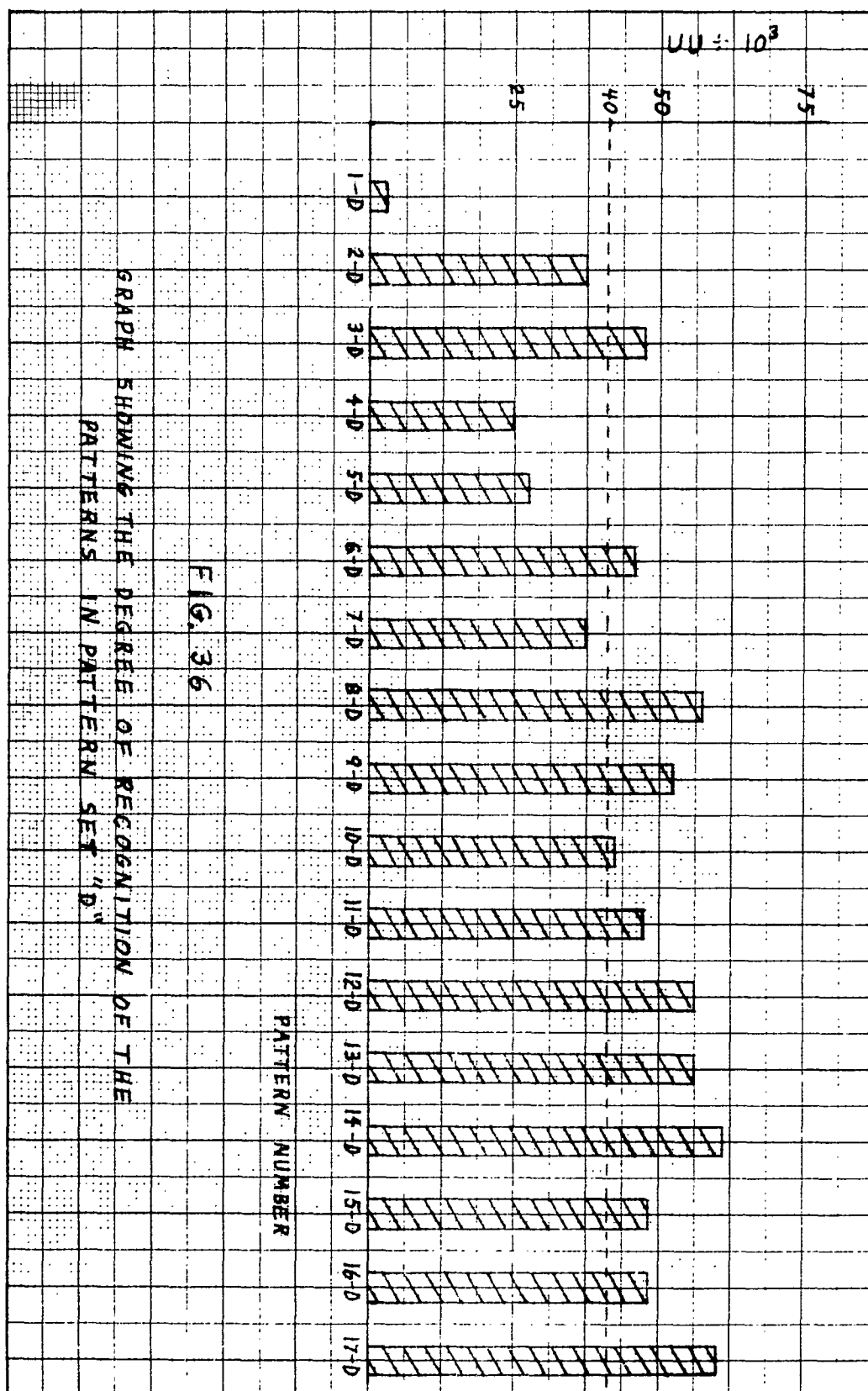
curves is taken as 100% recognition of a stored pattern, then any slight variation of this pattern produced less than 100% recognition. The human visual system can operate in a mode where there is no intermediate degree of recognition, ie, a pattern is either recognized or not recognized. This indicates the establishment of a threshold function for recognition, which could be duplicated on the model by selecting a certain value of UU for a threshold. If this threshold value is selected as 40,000, above which non-recognition occurs and below which recognition occurs, then a significant degree of pattern invariance recognition is shown by the model. Pattern 1-A and pattern #1-B would be recognized for rotations up to 23 degrees and 16 degrees respectively, and for vertical displacement of one cell width and 1/2 cell width respectively. Pattern #1-B and pattern #1-C would be recognized for size variations up to nearly one cell width and 1/2 cell width respectively. Pattern #1-C would be recognized through most of the shape variations in Fig. 34, and, using metric #4, it would be recognized for vertical displacements of more than two cell widths (Fig. 35). Most of the variations of the letter "A" in Fig. 36 would be recognized and none of the other letters would give recognition. Thus, with a threshold value of 40,000 for UU, the model would be capable of performing pattern invariance recognition for displacements of 1/2 cell width, rotations of 15

degrees, size variations of 1/2 cell width, and slight shape variations for stored patterns similar to the ones in pattern sets A,B,C, and D.

It is concluded that the results of this investigation are of some significance when it is considered that only a portion of the human visual system was simulated, that portion being the basic functional units of area 17 and the short intracortical fibers connecting adjacent units. However, the pattern invariance capabilities of this model are far short of those of the human visual system. It is recommended that further investigation be made by revising the model to include a simulation of the longer subcortical fibers which connect each functional unit of area 17 to many other functional units within area 17. The results obtained by testing this revised model may justify a further revision to include a simulation of areas 18 and 19 and the subcortical fibers connecting each functional unit in area 17 to many units in areas 18 and 19.

Bibliography

1. Doyle, W. "Operations Useful for Similarity-Invariant Pattern Recognition." Journal of the Association for Computing Machinery, 9:259-267 (April 1962).

2. Elias, P., et al. "Fourier Treatment of Optical Processes." Journal of the Optical Society of America, 42:127-134 (February 1952).

3. Hebb, D.O. A Textbook of Psychology. Philadelphia: W.B. Saunders Co., 1960.

4. Kabrisky, M. "A Spatially Iterated Memory Organ Patterned After the Cerebral Cortex." Preprints of the Papers Presented at the 16th National Meeting of the Association for Computing Machinery, 2c-3, 1-4 (September 1961).

5. Kohler, I. "Experiments With Goggles." Scientific American, 206:62-72 (May 1962).

6. Kopal, Z. Proceedings of a Symposium on Astronautical Optics and Related Subjects. New Youk: Interscience Publishers, Inc., 1956.

7. McLachlan, D. "The Role of Optics in Applying Correlation Functions to Pattern Recognition." Journal of the Optical Society of America, 52:454-459 (April 1962).

8. Polyak, S. The Vertebrate Visual System. Chicago: University of Chicago Press, 1957.

9. Roetling, P.G., and H.B. Hammill. Study of Spatial Filtering by Optical Diffraction for Pattern Recognition. Buffalo, N. Y.: Cornell Aeronautical Laboratory, Inc., (February 1962).

```
T1922          IF(B-0)74,70,70                                    Error Check
T1986    74     B=0
T2010          BB=0
T2034          L=K
T2058          M=J
T2082    70     UU=0*0+UU
T2130     4     CONTINUE
T2202          PRINT 100, ITNO, BB, L, M
T2262          PRINT 101, U, UU, UUU
T2310   100     FORMAT(/I4, 14X, F13.7, 5X, I3, 5X, I3)
T2422   101     FORMAT(/F14.7, 4X, F14.5, 5X, F14.5)
T2492          ITNO=ITNO+1
T2523          IF(SENSE SWITCH 3)43,53
T2543    53     IF(SENSE SWITCH 1)40,50
T2563    43     PAUSE
T2580          GO TO 34
T2588    50     DO 51 K=1,N
T2600          DO 51 J=1,N
T2612          SF(K,J)=SF(K,J )+A*DE(K,J)
T2840    51     SS(K,J)=SS(K,J)+AA*SF(K,J)
T3140          GO TO 52
T3148    40     PRINT 102
T3172          102 FORMAT(/,26H PRINT OF SF ARRAY FOLLOWS/)
T3258          DO 140 K=1,N
T3270          IF(SENSE SWITCH 1)24,26                          Output Statements
T3290    24 DO 23 J=1,N
T3302    20     PRINT 1000, SF(K,J)
T3386    23     CONTINUE
T3422   140 PRINT 1001
T3482  1000 FORMAT (F7.2)
T3504  1001 FORMAT (/)
T3526          IF(SENSE SWITCH 2)25,26
T3546    25     PRINT 103
T3570   103 FORMAT(/,34H PUNCH OF PRINTED SF ARRAY FOLLOWS)
T3668          PAUSE
T3680          DO 32 K=1,N
T3692          PUNCH 30, SF(K,1), SF(K,2), SF(K,3), SF(K,4), SF(K,5)
T3884    30     FORMAT (5F7.2)
T3926    32     PUNCH 30, SF(K,6), SF(K,7), SF(K,8), SF(K,9), SF(K,10)
T4154    26     PRINT 104
T4178          104 FORMAT(/,26H PRINT OF SS ARRAY FOLLOWS/)
T4264          DO 141 K=1,N
T4276          IF(SENSE SWITCH 1)27,153
T4296    27 DO 150 J=1,N
T4308          PRINT 1000, SS(K,J)
T4392   150     CONTINUE
T4428   141 PRINT 1001
T4488          IF (SENSE SWITCH 2)29,153
T4508    29     PRINT 151
T4532   151 FORMAT(/,34H PUNCH OF PRINTED SS ARRAY FOLLOWS)
T4630          PAUSE
T4642          DO 152 K=1,N
T4654          PUNCH 30, SS(K,1), SS(K,2), SS(K,3), SS(K,4), SS(K,5)
T4846   152     PUNCH 30, SS(K,6), SS(K,7), SS(K,8), SS(K,9), SS(K,10)
T5074   153     PRINT 154
T5098          154 FORMAT(/,26H PRINT OF DE ARRAY FOLLOWS/)
T5134          DO 142 K=1,N
T5196          IF(SENSE SWITCH 1)155,50
T5216   155 DO 157 J=1,N
T5228   156     PRINT 1000, DE(K,J)
```

79

GE/EE/63-11

```
T5312   157   CØNTINUE
T5348   142 PRINT 1001
T5408         GØ TØ 50
T5416         END
END ØF CØMPILATIØN T541534500
```

80

Appendix B

List of Metrics

Format

N, A, AA, C, CC, D, DD, R

G1, G2, G3, G4

H1, H2, H3, H4

P1, P2, P3, P4

Metric 1

10, .1, .01, 1., 1., 1., 1., 0.

.25, .25, .25, .25

.25, .25, .25, .25

.25, .25, .25, .25

Metric 2

10, .1, .01, 1., 1., 1., 1., 0.

.5, .25, .5, .25

.5, .25, .5, .25

.5, .25, .5, .25

Metric 3

10, .1, .ol, 1., 1., 1., 1., 0.

.25, .5, .25, .5

.25, .5, .25, .5

.25, .5, .25, .5

Metric 4

10, .1, .01, 1., 1., 1., 1., 0.

0., 0., 0., 0.

0., 0., 0., 0.

0., 0., 0., 0.

Metric 5

10, .1, .01, 1., 1., 1., 1., 0.

.5, .5, .5, .5

.5, .5, .5, .5

.5, .5, .5, .5

Appendix C
Computer Data

STORING PATTERN 1-A WITH METRIC 1

```
        2            -64.4383460      7     2
   2046.5712000    125463.26000          -2038.84390


        3            -51.3743100      7     2
   1626.4664000·     79977.39100          -1617.69530
        4            -40.7089860      7     2
   1285.3397000      50517.58100          -1276.61280
        5            -32.0079860      7     2
   1009.2854000      31542.27100          -1000.50090

-25.5763450      6         2
    799.1120500         19405.58500          -777.10124


        7            -20.5291330      6     2
    627.0192500       11712.92400          -596.46149
PRINT ØF SF ARRAY FØLLØWS        .00     .00     .00     .00     .00     .00
 .00     .00     .00     .00
       .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
     -.01    -.01    -.01    -.01    -.01    -.01    -.01    -.01    -.01    -.01
      .33     .27     .28     .28     .28     .28     .28     .28     .27     .33
    -3.59   -2.89   -2.94   -2.94   -2.94   -2.94   -2.94   -2.94   -2.89   -3.59
   -32.58  -36.21  -35.87  -35.89  -35.89  -35.89  -35.89  -35.87  -36.21  -32.58
   -36.50  -39.38  -39.10  -39.12  -39.12  -39.12  -39.12  -39.10  -39.38  -36.50
   -36.14  -39.07  -38.79  -38.81  -38.81  -38.81  -38.81  -38.79  -39.07  -36.14
   -36.49  -39.37  -39.09  -39.10  -39.10  -39.10  -39.10  -39.09  -39.37  -36.49
   -32.91  -36.49  -36.16  -36.17  -36.17  -36.17  -36.17  -36.16  -36.49  -32.91

PRINT ØF SS ARRAY FØLLØWS        .00     .00     .00     .00     .00     .00
 .00     .00     .00     .00
       .00     .00     .00     .00     .00     .00     .00     .00     .00     .00

PRINT ØF DE ARRAY FØLLØWS
        8            -16.3452160      6     2
    486.1280500       6894.74360          -450.50147
PRINT ØF SF ARRAY FØLLØWS        .00     .00     .00     .00     .00     .00
 .00     .00     .00     .00
     -.02    -.01    -.01    -.01    -.01    -.01    -.01    -.01    -.01    -.02
      .38     .31     .31     .31     .31     .31     .31     .31     .31     .38
    -3.54   -2.72   -2.79   -2.79   -2.79   -2.79   -2.79   -2.79   -2.72   -3.54
   -34.67  -38.26  -37.87  -37.89  -37.89  -37.89  -37.89  -37.87  -38.26  -34.67
   -38.59  -41.30  -40.99  -41.00  -41.00  -41.00  -41.00  -40.99  -41.30  -38.59
   -38.16  -40.95  -40.63  -40.65  -40.65  -40.65  -40.65  -40.63  -40.95  -38.16
   -38.57  -41.28  -40.97  -40.99  -40.98  -40.98  -40.99  -40.97  -41.28  -38.57
   -35.05  -38.57  -38.19  -38.21  -38.21  -38.21  -38.21  -38.19  -38.57  -35.05
```

```
PRINT OF SS ARRAY FOLLOWS      .00     .00     .00     .00     .00     .00
.00     .00     .00     .00
        .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
        .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
        .01     .01     .01     .01     .01     .01     .01     .01     .01     .01
       -.23    -.20    -.20    -.20    -.20    -.20    -.20    -.20    -.20    -.23
      -1.83   -2.11   -2.10   -2.10   -2.10   -2.10   -2.10   -2.10   -2.11   -1.88
      -2.12   -2.33   -2.32   -2.32   -2.32   -2.32   -2.32   -2.32   -2.33   -2.12
      -2.11   -2.32   -2.30   -2.30   -2.30   -2.30   -2.30   -2.30   -2.32   -2.11
      -2.12   -2.33   -2.32   -2.32   -2.32   -2.32   -2.32   -2.32   -2.33   -2.12
      -1.89   -2.12   -2.11   -2.11   -2.11   -2.11   -2.11   -2.11   -2.12   -1.89

PRINT OF DE ARRAY FOLLOWS      .00     .00     .00     .00     .00     .00
.00     .00     .00     .00
        .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
       -.07    -.05    -.05    -.05    -.05    -.05    -.05    -.05    -.05    -.07
        .46     .23     .26     .26     .26     .26     .26     .26     .23     .46
       1.04    2.13    1.89    1.91    1.91    1.91    1.91    1.89    2.13    1.04
```

```
-17.22 -16.34 -15.84 -15.92 -15.91 -15.91 -15.92 -15.84 -16.34 -17.22
-16.65 -14.44 -14.21 -14.26 -14.26 -14.26 -14.26 -14.21 -14.44 -16.65
-16.03 -14.10 -13.84 -13.90 -13.89 -13.89 -13.90 -13.84 -14.10 -16.03
-16.53 -14.39 -14.16 -14.21 -14.21 -14.21 -14.21 -14.16 -14.39 -16.58
-17.69 -16.57 -16.11 -16.18 -16.17 -16.17 -16.18 -16.11 -16.57 -17.69
```

```
  9                    -12.8745610      6        2
370.8062000             3924.91650              -332.66213
 10                     -9.9936610       6        2
276.4415600             2134.66950              -237.61964
 11                     -7.6007910       6        2
199.3639300             1089.83360              -161.05339
 12                     -5.6121190       6        2
136.9220000              509.91658               -99.45728
 13                     -3.9585110       6        2
 86.2276620              214.83679               -49.98690
 14                     -2.5829250       6        2
 44.8575410               89.89621               -10.33471

 15                      2.1912481       5        9
 47.0323460               62.80157                21.37070
 16                      2.0414548       5        2
 57.8450000               88.62052                46.64681
 17                      2.4828060       7        2
 70.4415010              139.95915                66.72389
 18                      3.0009180       7        2
 86.4631110              200.57196                82.59918
```

```
PRINT OF SF ARRAY FOLLOWS      .00     .00     .00     .00     .00     .00
.00     .00     .00     .00
        .01     .00     .00     .00     .00     .00     .00     .00     .00     .01
       -.09    -.04    -.05    -.05    -.05    -.05    -.05    -.05    -.04    -.09
        .55     .22     .30     .29     .29     .29     .29     .30     .22     .55
      -1.73    -.42    -.75    -.70    -.71    -.71    -.70    -.75    -.42   -1.73
     -42.35  -44.32  -43.70  -43.80  -43.79  -43.79  -43.80  -43.70  -44.32  -42.35
     -44.65  -44.97  -44.76  -44.80  -44.80  -44.80  -44.80  -44.76  -44.97  -44.65
     -43.91  -44.66  -44.35  -44.41  -44.40  -44.40  -44.41  -44.35  -44.66  -43.91
     -44.55  -44.93  -44.71  -44.75  -44.75  -44.75  -44.75  -44.71  -44.93  -44.55
     -42.90  -44.54  -44.00  -44.09  -44.08  -44.08  -44.09  -44.00  -44.54  -42.90
```

PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS   .00   .00   .00   .00   .00   .00
.00   .00   .00   .00
     .00   .00   .00   .00   .00   .00   .00   .00   .00   .00
     .00   .00   .00   .00   .00   .00   .00   .00   .00   .00
     .06   .04   .04   .04   .04   .04   .04   .04   .04   .06
    -.49   -.34   -.37   -.36   -.36   -.36   -.36   -.37   -.34   -.49
   -5.91   -6.42   -6.35   -6.36   -6.36   -6.36   -6.36   -6.35   -6.42   -5.91
   -6.47   -6.81   -6.77   -6.77   -6.77   -6.77   -6.77   -6.77   -6.81   -6.47
   -6.39   -6.76   -6.71   -6.72   -6.71   -6.71   -6.72   -6.71   -6.76   -6.39
   -6.46   -6.81   -6.76   -6.77   -6.77   -6.77   -6.77   -6.76   -6.81   -6.46
   -5.97   -6.46   -6.40   -6.40   -6.40   -6.40   -6.40   -6.40   -6.46   -5.97

PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS   .00   .00   .00   .00   .00   .00
.00   .00   .00   .00
     .01   .00   .00   .00   .00   .00   .00   .00   .00   .01
    -.04   .01   .00   .00   .00   .00   .00   .00   .01   -.04
    -.10   -.30   -.20   -.22   -.22   -.22   -.22   -.20   -.30   -.10
    1.83   1.72   1.51   1.58   1.57   1.57   1.58   1.51   1.72   1.83
    -.71   .96   .95   .88   .89   .89   .88   .95   .96   -.71
    1.21   3.00   2.66   2.69   2.69   2.69   2.69   2.66   3.00   1.21
    1.20   2.65   2.46   2.46   2.46   2.46   2.46   2.46   2.65   1.20
    1.26   2.98   2.66   2.68   2.69   2.69   2.68   2.66   2.98   1.26
    -.60   1.27   1.15   1.11   1.12   1.12   1.11   1.15   1.27   -.60

STORING PATTERN 1-A WITH METRIC 2

0	-125.0000000	7	2
4000.0000000	460000.00000		-4000.00000
1	-95.0156300	7	9
3022.8248000	263663.29000		-3002.62480
2	-71.8591520	7	2
2272.9565000	149920.91000		-2242.55750
3	-53.9776650	7	2
1697.7116000	84362.65800		-1663.62690
4	-40.1717920	7	2
1256.6101000	46829.94900		-1222.93150
5	-29.5150870	7	2
922.8224500	25534.33400		-887.70787
6	-21.7043060	6	2
683.2345800	13597.98500		-632.93819
7	-16.7156160	6	2
506.0210100	7020.07840		-439.52190
8	-12.8023180	6	2
364.4101100	3482.34130		-292.87760
9	-9.7238220	6	2
254.2921300	1648.27790		-181.87626
10	-7.2944400	6	2

```
   168.6150500           752.53325           -98.02510
11                      -5.3707880      6      2
   101.9184600           360.74414           -34.84459
12                       4.2438769      5      9
    75.4964820           229.41026            12.60734
13                       4.1210578      5      2
    93.2963160           224.35367            48.09962
14                       3.9585186      5      2
   105.7203600           273.46441            74.50490
15                       3.7729315      5      9
   113.7902500           339.44398            94.01240
```

PRINT ØF SF ARRAY FØLLØWS   -.01   .00   .00   .00   .00   .00   .00   .
00   .00   -.01

```
    .10     .06     .07     .07     .07     .07     .07     .07     .06     .10
   -.60    -.36    -.39    -.39    -.39    -.39    -.39    -.39    -.36    -.60
   2.30    1.26    1.45    1.43    1.43    1.43    1.43    1.45    1.26    2.30
  -5.03   -2.35   -2.88   -2.82   -2.82   -2.82   -2.82   -2.88   -2.35   -5.03
 -40.03  -43.05  -42.38  -42.47  -42.46  -42.46  -42.47  -42.38  -43.05  -40.03
 -47.47  -46.74  -46.79  -46.80  -46.79  -46.79  -46.80  -46.79  -46.74  -47.47
 -43.98  -44.76  -44.55  -44.58  -44.58  -44.58  -44.58  -44.55  -44.76  -43.98
 -46.88  -46.39  -46.40  -46.41  -46.41  -46.41  -46.41  -46.40  -46.39  -46.88
 -42.33  -44.32  -43.84  -43.90  -43.89  -43.89  -43.90  -43.84  -44.32  -42.33
```

PUNCH ØF PRINTED SF ARRAY FØLLØWS

PRINT ØF SS ARRAY FØLLØWS   .00   .00   .00   .00   .00   .00   .00   .
00   .00   .00

```
    .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
   -.03    -.02    -.02    -.02    -.02    -.02    -.02    -.02    -.02    -.03
    .19     .14     .15     .15     .15     .15     .15     .15     .14     .19
   -.86    -.64    -.67    -.67    -.67    -.67    -.67    -.67    -.64    -.86
  -4.72   -5.16   -5.11   -5.11   -5.11   -5.11   -5.11   -5.11   -5.16   -4.72
  -5.79   -5.95   -5.94   -5.94   -5.94   -5.94   -5.94   -5.94   -5.95   -5.79
  -5.52   -5.76   -5.74   -5.74   -5.74   -5.74   -5.74   -5.74   -5.76   -5.52
  -5.75   -5.93   -5.91   -5.91   -5.91   -5.91   -5.91   -5.91   -5.93   -5.75
  -4.92   -5.30   -5.26   -5.26   -5.26   -5.26   -5.26   -5.26   -5.30   -4.92
```

PUNCH ØF PRINTED SS ARRAY FØLLØWS

PRINT ØF DE ARRAY FØLLØWS   -.03   -.02   -.02   -.02   -.02   -.02   -.02   -.
02   -.02   -.03

```
    .19     .07     .10     .10     .10     .10     .10     .10     .07     .19
   -.57    -.09    -.21    -.19    -.19    -.19    -.19    -.21    -.09    -.57
    .40    -.74    -.36    -.42    -.41    -.41    -.42    -.36    -.74     .40
   2.77    3.77    3.13    3.26    3.24    3.24    3.26    3.13    3.77    2.77
  -1.10    -.85    -.39    -.52    -.50    -.50    -.52    -.39    -.85   -1.10
   1.07    3.58    2.99    3.07    3.06    3.06    3.07    2.99    3.58    1.07
   2.59    3.00    3.04    3.01    3.02    3.02    3.01    3.04    3.00    2.59
   1.61    3.65    3.19    3.24    3.24    3.24    3.24    3.19    3.65    1.61
  -1.50    -.10    -.03    -.09    -.08    -.08    -.09    -.03    -.10   -1.50
```

```
16                       4.1652310      9      2
   120.6436900           404.19094           108.28964
```

STORING PATTERN 1-A WITH METRIC 3

0	-125.0000000	7	2
4000.0000000	477500.00000		-4000.00000
1	-95.0156300	7	2
3007.6747000	272339.95000		-3002.62470
2	-71.8033600	7	2
2249.5197000	153994.83000		-2242.55750
3	-53.8413980	7	2
1670.6396000	86082.31400		-1663.62670
4	-40.5201930	6	2
1239.3314000	47381.40400		-1222.93140
5	-30.9943340	6	2
918.6447500	25535.09300		-887.70784
6	-23.4853710	6	2
671.3981600	13363.72300		-632.93821
7	-17.5606950	6	2
480.8345200	6707.73350		-439.52186
8	-12.8821640	6	2
334.3391600	3166.41620		-292.87758
9	-9.1851480	6	2
222.0412600	1361.15440		-181.87627
10	-6.2622760	6	2
136.0188700	505.60267		-98.02511
11	-3.9509050	6	2
69.9607250	155.35951		-34.84464
12	2.6560663	5	2
42.0636700	62.46703		12.60731
13	2.4317432	5	2
57.4688690	91.08150		48.09960

```
PRINT ØF SF ARRAY FØLLØWS      .00    .00    .00    .00    .00    .00    .00    .
00   .00    .00
      .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
     -.05   -.01   -.02   -.02   -.02   -.02   -.02   -.02   -.01   -.05
      .46    .08    .19    .17    .18    .18    .17    .19    .08    .46
    -2.34   -.01   -.81   -.65   -.67   -.67   -.65   -.81   -.01  -2.34
   -41.25 -46.76 -44.53 -45.03 -44.96 -44.96 -45.03 -44.53 -46.76 -41.25
   -44.06 -46.86 -45.55 -45.87 -45.82 -45.82 -45.87 -45.55 -46.86 -44.06
   -43.49 -46.75 -45.30 -45.64 -45.59 -45.59 -45.64 -45.30 -46.75 -43.49
   -44.01 -46.85 -45.52 -45.84 -45.79 -45.79 -45.84 -45.52 -46.85 -44.01
   -41.72 -46.84 -44.73 -45.20 -45.14 -45.14 -45.20 -44.73 -46.84 -41.72

PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS       .00    .00    .00    .00    .00    .00    .00    .
00   .00    .00
      .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
      .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
      .03    .01    .02    .02    .02    .02    .02    .02    .01    .03
     -.34   -.18   -.22   -.21   -.21   -.21   -.21   -.22   -.18   -.34
    -4.04  -4.79  -4.64  -4.66  -4.66  -4.66  -4.66  -4.64  -4.79  -4.04
    -4.42  -5.00  -4.88  -4.90  -4.90  -4.90  -4.90  -4.88  -5.00  -4.42
    -4.38  -4.98  -4.86  -4.88  -4.87  -4.87  -4.88  -4.86  -4.98  -4.38




    -4.42  -5.00  -4.88  -4.90  -4.90  -4.90  -4.90  -4.88  -5.00  -4.42
    -4.07  -4.81  -4.66  -4.68  -4.68  -4.68  -4.68  -4.66  -4.81  -4.07
```

```
PUNCH OF PRINTED SS ARRAY FOLLOWS
PRINT OF DE ARRAY FOLLOWS      .00     .00     .00     .00     .00     .00     .00     .
00    .00    .00
      .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
    -.06    .03    .00    .00    .00    .00    .00    .00    .03   -.06
     .13   -.40   -.10   -.18   -.16   -.16   -.18   -.10   -.40    .13
    1.48   2.43   1.31   1.71   1.63   1.63   1.71   1.31   2.43   1.48
   -3.62   -.67    .18   -.48   -.30   -.30   -.48    .18   -.67  -3.62
   -2.28   2.15   1.59   1.41   1.49   1.49   1.41   1.59   2.15  -2.28
   -2.02   1.69   1.51   1.22   1.32   1.32   1.22   1.51   1.69  -2.02
   -2.22   2.12   1.60   1.41   1.49   1.49   1.41   1.60   2.12  -2.22
   -3.76   -.27    .28   -.30   -.13   -.13   -.30    .28   -.27  -3.76
```

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A

(PATTERN 1-A STORED WITH METRIC 1)

```
0                     -87.7975000       4        2          160001000000
1645.8200000         123121.66000               -1518.02000
1                     -72.3411760       4        2
1340.2829000          82302.73800               -1183.47790
2                     -59.4837390       4        2
1089.7859000          54938.51700                -913.06305
3                     -48.7839840       4        2
834.5267600           36615.99000                -694.61435
4                     -39.8764640       4        2
739.5342300           24368.07200                -518.26747
5                     -32.4583660       4        2
627.1479400           16199.43300                -376.02460
6                     -26.2786590       4        2
547.0128000           10767.95700                -261.40153
7                     -21.1291480       4        2
477.3148300            7170.93780                -169.14177
8                     -16.8370320       4        2
418.0807200            4801.27820                 -94.93491
9                     -13.2590500       4        2
366.5287900            3250.89240                 -35.47798
10                    -10.2759490       4        2
322.0455300            2245.64660                  12.17651
11                     -7.7898080       4        2
283.8269700            1601.59130                  50.24512
PRINT OF SF ARRAY FOLLOWS      -.04   -.03   -.03   -.03   -.03   -.03   -.03
03   -.03   -.04
      .52    .35    .37    .37    .37    .37    .37    .37    .35    .52
   -3.19  -1.98  -2.17  -2.15  -2.15  -2.15  -2.15  -2.17  -1.98  -3.19
  -39.11 -42.63 -41.94 -42.03 -42.02 -42.02 -42.03 -41.94 -42.63 -39.11
  -39.66 -41.80 -41.76 -41.65 -41.70 -41.70 -41.68 -41.76 -41.80 -39.66
  -43.91 -43.36 -42.99 -43.14 -43.10 -43.10 -43.14 -42.99 -43.36 -43.91
  -40.91 -40.18 -40.31 -40.30 -40.30 -40.30 -40.30 -40.31 -40.18 -40.91
  -40.88 -40.67 -40.54 -40.59 -40.59 -40.59 -40.59 -40.54 -40.67 -40.88
  -41.30 -40.54 -40.64 -40.63 -40.63 -40.63 -40.63 -40.64 -40.54 -41.30
  -41.19 -41.28 -40.95 -41.06 -41.04 -41.04 -41.06 -40.95 -41.28 -41.19
```

```
PRINT OF SS ARRAY FOLLOWS    .00     .00     .00     .00     .00     .00     .00    .
00    .00     .00
      .03     .02     .02     .02     .02     .02     .02     .02     .02     .03
     -.34    -.27    -.28    -.28    -.28    -.28    -.28    -.28    -.27    -.34
    -2.93   -3.32   -3.23   -3.28   -3.28   -3.29   -3.28   -3.28   -3.32   -2.93
    -3.61   -3.67   -3.72   -3.70   -3.70   -3.70   -3.70   -3.72   -3.67   -3.61
   -10.84  -11.41  -11.29  -11.31  -11.31  -11.31  -11.31  -11.29  -11.41  -10.84
   -11.18  -11.48  -11.44  -11.44  -11.44  -11.44  -11.44  -11.44  -11.48  -11.18
   -11.06  -11.44  -11.37  -11.39  -11.38  -11.38  -11.39  -11.37  -11.44  -11.06
   -11.19  -11.50  -11.44  -11.46  -11.46  -11.46  -11.46  -11.44  -11.50  -11.19
   -10.62  -11.19  -11.08  -11.09  -11.09  -11.09  -11.09  -11.08  -11.19  -10.62

PRINT OF DE ARRAY FOLLOWS   -.07    -.03    -.04    -.04    -.04    -.04    -.04    -.
04    -.03    -.07
      .24    -.04     .02     .02     .02     .02     .02     .02    -.04     .24
     1.97    2.65    2.33    2.39    2.38    2.38    2.39    2.33    2.65    1.97
    -9.75   -7.78   -7.46   -7.58   -7.56   -7.56   -7.58   -7.46   -7.78   -9.75
    -8.64   -7.14   -6.91   -6.93   -6.94   -6.94   -6.93   -6.91   -7.14   -8.64
     4.80    6.32    5.90    5.91    5.93    5.93    5.91    5.90    6.32    4.80
     4.19    4.35    4.16    4.23    4.21    4.21    4.23    4.16    4.35    4.19
     3.63    4.02    3.91    3.92    3.92    3.92    3.92    3.91    4.02    3.63
     3.94    4.34    4.12    4.18    4.17    4.17    4.18    4.12    4.34    3.94
     3.05    3.94    3.72    3.72    3.73    3.73    3.72    3.72    3.94    3.05

   12                    6.3451790           6       2
   251.4503300           1195.49190                  80.56389
```

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A

(METRIC 2 USED IN STORING PATTERN 1-A)

```
0                -89.0800000      4        2
1662.5950000     121797.60000              -1522.13500
1                -73.5271250      4        2
1356.0166000     81285.92800               -1185.82780
2                -60.5785560      4        2
1104.5103000     54162.90900               -914.03357
3                -49.7930090      4        2
898.2490800      36028.33500               -694.51238
4                -40.8049220      4        2
729.1840300      23925.97100               -517.33803
5                -33.3113270      4        2
616.1172500      15869.43200               -374.46225
6                -27.0610170      4        2
538.0216600      10523.92300               -259.36026
7                -21.8455980      4        2
470.5559500      6992.54870                -166.74357
8                -17.4921080      4        2
412.2947400      4672.83180                -92.32562
9                -13.8569230      4        2
361.9958400      3160.30310                -32.63294
10               -10.8207150      4        2
318.5989000      2183.64840                15.14864
11               -8.2842920       4        2
281.5121200      1561.10250                53.29877
```

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A
(METRIC 3 USED IN STORING PATTERN 1-A)

0	-87.7150000	4	2
1623.4250000	123477.88000		-1558.06500

THE FOLLOWING SETS OF PATTERN COMPARISON DATA WERE
OBTAINED BY USING THE STORED SF ARRAY OF PATTERN 1-A
AS THE SS ARRAY DURING THE COMPARISON. THE SF ARRAY
EQUALS ZERO. METRIC 1 USED IN STORING PATTERN 1-A AND
IN EACH COMPARISON.

COMPARING PATTERN 1-A WITH STORED PATTERN 1-A

0	-11.0150000	8	3
348.4150000	3656.31590		-348.13500
1	-8.8070770	8	3
273.3631900	2364.25550		-278.03032
2	-7.0460260	6	4
222.5896900	1520.64730		-221.25434
3	-5.7758690	6	4
179.4507400	971.62421		-175.29140

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A

0	-83.1200000	5	3
1948.3150000	131860.30000		-1948.13500
1	-72.2997980	4	2
1561.2908000	87537.31200		-1556.09080
2	-59.4018580	4	2
1246.5927000	57929.17400		-1238.74370
3	-48.6771020	4	2
990.8079400	38177.00900		-981.94735

COMPARING PATTERN 3-A WITH STORED PATTERN 1-A

0	77.1800000	6	2
1427.0450000	96840.93200		1251.86500
1	63.7147330	7	2
1155.9605000	65204.55700		1000.03240
2	52.5735100	7	2
950.5055000	43782.63900		796.23661
3	43.2733780	7	2
779.1956100	29291.33500		631.36470

COMPARING PATTERN 8-A WITH STORED PATTERN 1-A

0	-87.9350000	5	9
976.4000000	45887.37000		-348.13500
1	-72.7670110	5	9
791.7542600	31441.12500		-278.03033
2	-60.0806640	5	9
642.2272100	21544.62100		-221.25426
3	-49.4656410	5	9
520.7804300	14761.12200		-175.29136

COMPARING PATTERN 9-A WITH STORED PATTERN 1-A

0	-100.3175000	4	9
1353.4450000	78580.11700		-348.13500
1	-81.9591730	4	9
1100.9943000	52646.96300		-278.03033
2	-66.7583260	4	9
889.7649200	35180.42600		-221.25427
3	-54.1735250	4	9
716.7860000	23432.41000		-175.29132

COMPARING PATTERN 4-A WITH STORED PATTERN 1-A

0	-75.6200000	5	3
1077.4050000	53053.17800		-1048.13500
1	-63.4232610	5	2
858.0473500	36252.60800		-849.88656
2	-53.2868510	5	2
695.9379300	24810.62300		-687.82964
3	-44.7225530	5	2
564.6406200	17003.05900		-555.28849

COMPARING PATTERN 5-A WITH STORED PATTERN 1-A

0	-83.1200000	5	3
2401.9450000	177204.90000		-1148.13500
1	-72.2997980	4	2
1934.4004000	118396.62000		-917.06077
2	-59.4018580	4	2
1569.8156000	78870.67600		-730.03038
3	-48.6771020	4	2
1269.6983000	52337.95700		-578.69461

COMPARING PATTERN 7-A WITH STORED PATTERN 1-A

```
0                -100.3175000      4        9
3088.1450000      257072.88000            -348.13500
1                -80.6966730       4        9
2483.9276000      167888.59000            -278.03029
2                -64.6671200       4        9
1997.8357000      109085.08000            -221.25419
3                -51.5775170       4        9
1601.1347000      70430.39300            -175.29131
4                -40.8944000       4        9
1277.0117000      45116.27500            -138.09991
5                -32.1808550       4        9
1012.7165000      28616.84800            -108.02209
```

STORING PATTERN 1-B WITH METRIC 1

```
0                -100.0000000      6        2
2400.0000000      205000.00000            -2400.00000
1                -80.7468750       6        2
1927.1924000      134739.95000            -1917.09280
```

PRINT ØF SF ARRAY FØLLØWS

```
  .00   .00   .00   .00   .00   .00   .00   .00   .00
  .00   .00   .00   .00   .00   .00   .00   .00   .00
  .00   .00   .00   .00   .00   .00   .00   .00   .00
-1.25 -1.25 -1.25 -1.25 -1.25 -1.25 -1.25 -1.25 -1.25 -1.25
-7.50 -8.75 -8.75 -8.75 -8.75 -8.75 -8.75 -8.75 -8.75 -7.50
-8.75 -10.00 -10.00 -10.00 -10.00 -10.00 -10.00 -10.00 -10.00 -8.75
-7.50 -8.75 -8.75 -8.75 -8.75 -8.75 -8.75 -8.75 -8.75 -7.50
```

PRINT ØF SS ARRAY FØLLØWS

PRINT ØF DE ARRAY FØLLØWS

```
2                -64.9213020       6        2
1541.7209000      88191.96100            -1526.26720
3                -51.9211870       6        2
1227.5953000      57422.04100            -1210.06110
4                -41.2500270       6        2
971.7473200       37140.90300            -954.31440
5                -32.4983280       6        2
765.0351600       23823.16300            -747.55026
6                -25.5302110       5        2
624.3491400       15120.33200            -580.46270
7                -20.4793280       5        2
506.4354700       9469.13430            -445.50964
8                -16.2946820       5        2
407.5889100       5829.93270            -336.57800
9                -12.8259510       5        2
324.7132000       3512.27830            -248.71400
```

```
10                      -9.9492220        5       2
   255.2207000          2058.39250            -177.90328
11                      -7.5623140        5       2
   197.1590200          1165.44700            -120.89396
12                      -5.5809280        5       2
   149.5980000           633.69381             -75.05141
13                      -3.9355010        7       2
   110.3357400           331.87196             -38.24204
14                      -2.5685930        7       2
    77.9998500           174.14894              -8.73774
15                       2.1866732        8       2
    65.3960100           104.75457              14.86052
16                       2.0975730        6       2
    55.6262250            87.75652              33.68556
```

PRINT ØF SF ARRAY FØLLØWS

```
   .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  -.08    -.04    -.05    -.05    -.05    -.05    -.05    -.05    -.04    -.08
   .56     .28     .33     .33     .33     .33     .33     .33     .28     .56
 -2.12    -.81   -1.10   -1.06   -1.07   -1.07   -1.06   -1.10    -.81   -2.12
-41.90  -44.25  -43.64  -43.72  -43.71  -43.71  -43.72  -43.64  -44.25  -41.90
-45.23  -45.68  -45.46  -45.50  -45.50  -45.50  -45.50  -45.46  -45.68  -45.23
-41.90  -44.25  -43.64  -43.72  -43.71  -43.71  -43.72  -43.64  -44.25  -41.90
 -2.12    -.81   -1.10   -1.06   -1.07   -1.07   -1.06   -1.10    -.81   -2.12
   .56     .28     .33     .33     .33     .33     .33     .33     .28     .56
  -.08    -.04    -.05    -.05    -.05    -.05    -.05    -.05    -.04    -.08
```

PUNCH ØF PRINTED SF ARRAY FØLLØWS

PRINT ØF SS ARRAY FØLLØWS

```
   .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
   .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
   .05     .03     .04     .04     .04     .04     .04     .04     .03     .05
  -.46    -.33    -.35    -.35    -.35    -.35    -.35    -.35    -.33    -.46
 -5.06   -5.53   -5.47   -5.48   -5.48   -5.48   -5.48   -5.47   -5.53   -5.06
 -5.63   -5.95   -5.91   -5.91   -5.91   -5.91   -5.91   -5.91   -5.95   -5.63
 -5.06   -5.53   -5.47   -5.48   -5.48   -5.48   -5.48   -5.47   -5.53   -5.06
  -.46    -.33    -.35    -.35    -.35    -.35    -.35    -.35    -.33    -.46
   .05     .03     .04     .04     .04     .04     .04     .04     .03     .05
   .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
```

PUNCH ØF PRINTED SS ARRAY FØLLØWS

PRINT ØF DE ARRAY FØLLØWS

```
   .01     .00     .00     .00     .00     .00     .00     .00     .00     .01
  -.05     .00    -.01    -.01    -.01    -.01    -.01    -.01     .00    -.05
  -.03    -.27    -.17    -.19    -.18    -.18    -.19    -.17    -.27    -.03
  1.96    2.03    1.79    1.85    1.84    1.84    1.85    1.79    2.03    1.96
 -2.22    -.48    -.42    -.49    -.48    -.48    -.49    -.42    -.48   -2.22
  -.23    2.09    1.70    1.73    1.73    1.73    1.73    1.70    2.09    -.23
 -2.22    -.48    -.42    -.49    -.48    -.48    -.49    -.42    -.48   -2.22
  1.96    2.03    1.79    1.85    1.84    1.84    1.85    1.79    2.03    1.96
```

```
17                       2.7781910        6       2
    55.9839550           100.26452              48.65413
```

THE FOLLOWING SETS OF PATTERN COMPARISON DATA WERE
OBTAINED BY USING THE STORED SF ARRAY OF PATTERN 1-B
AS THE SS ARRAY DURING THE COMPARISON. THE SF ARRAY
IS SET EQUAL TO ZERO. METRIC 1 USED IN STORING
PATTERN 1-B AND IN EACH COMPARISON.

COMPARING PATTERN 1-B WITH STORED PATTERN 1-B

0	−10.3025000	5	4
247.7200000	2457.32780		−246.85000
1	−8.4926440	5	4
204.8781200	1634.78320		−197.04379
2	−6.9969100	5	4
170.5379600	1085.57480		−156.75796
3	−5.7593440	5	4
141.8543900	719.16050		−124.18316

COMPARING PATTERN 2-B WITH STORED PATTERN 1-B

0	−75.1050000	4	3
1525.2400000	85300.43900		−246.85000
1	−62.9606140	4	2
1238.9646000	59200.96400		−197.04392
2	−52.8839510	4	2
1002.1126000	41091.89400		−156.75785
3	−44.3659570	4	2
818.5701700	28515.95200		−124.18294

COMPARING PATTERN 3-B WITH STORED PATTERN 1-B

0	−87.7900000	3	2
2925.2300000	222202.63000		−246.85000
1	−72.2909210	3	2
2380.1344000	149699.96000		−199.56846
2	−59.3990830	3	2
1930.7190000	100443.46000		−160.62130
3	−48.6737120	3	2
1560.2753000	67047.51400		−128.56534

COMPARING PATTERN 4-B WITH STORED PATTERN 1-B

0	-100.2900000	3	2
4060.9800000	334219.31000		-146.85000
1	-81.3190460	3	2
3321.2747000	223883.73000		-132.39390
2	-65.6382200	3	2
2709.8261000	149382.52000		-118.35627
3	-52.6869230	3	2
2204.3515000	99183.44000		-105.00536

COMPARING PATTERN 5-B WITH STORED PATTERN 1-B

0	-75.1050000	8	3
1525.2400000	85300.44100		-246.85000
1	-62.9606140	8	2
1236.4665000	59200.16300		-199.56890
2	-52.8839510	8	2
998.2492200	41089.92700		-160.62144
3	-44.3659570	8	2
814.1879700	28513.30500		-128.56526

COMPARING PATTERN 6-B WITH STORED PATTERN 1-B

0	-87.7900000	9	2
2825.2400000	220951.63000		-146.85000
1	-72.2909210	9	2
2313.0035000	149136.12000		-132.39350
2	-59.3990890	9	2
1888.6773000	100221.42000		-118.35606
3	-48.6739290	9	2
1537.1754000	66979.64200		-105.00536

COMPARING PATTERN 7-B WITH STORED PATTERN 1-B

0	-100.2900000	9	2
3360.9900000	272961.56000		553.15000
1	-81.3190460	9	2
2749.4630000	183007.50000		439.46226
2	-65.6302570	9	2
2243.5383000	122190.30000		348.15552
3	-52.6679070	9	2
1824.9694000	81168.19400		274.83793

COMPARING PATTERN 8-B WITH STORED PATTERN 1-B

```
0               -75.1050000         4           8
1215.0300000   59757.94200                  -246.85000
1               -63.1545560         4           8
990.5266900    41533.58900                  -198.62197
2               -53.0857930         4           8
806.8124200    28877.66600                  -159.21249
3               -44.5935040         4           8
657.6654800    20085.36700                  -127.02096
```

COMPARING PATTERN 9-B WITH STORED PATTERN 1-B

```
0               -100.2900000        3           9
1995.6450000   134429.29000                 -109.35000
1               -82.8971710         3           9
1643.7889000   92097.39000                  -93.00016
2               -68.3478650         3           9
1350.9830000   62908.24400                  -78.83496
3               -56.1751480         3           9
1107.8030000   42810.34900                  -66.58643
```

COMPARING PATTERN 10-B WITH STORED PATTERN 1-B

```
0               -100.2175000        3           7
2684.5400000   195685.98000                 -246.85000
1               -81.8774800         9           4
2193.8133000   132159.58000                 -198.62194
2               -66.6356610         9           4
1787.9548000   88937.93900                  -159.23645
3               -53.9749060         9           4
1452.4537000   59593.54100                  -127.03141
```

COMPARING PATTERN 11-B WITH STORED PATTERN 1-B

```
0               -100.2150000        3           5
2663.9400000   186622.25000                 -246.85000
1               -82.5058520         9           5
2182.9370000   125649.21000                 -197.04338
2               -67.7656200         9           5
1784.8741000   84318.52800                  -156.75751
3               -55.4956350         9           5
1454.9462000   56362.18800                  -124.18305
```

COMPARING PATTERN 12-B WITH STORED PATTERN 1-B

0	-75.1050000	4	3
1215.0300000	5957.94000		-246.85000
1	-63.1545560	4	3
990.5266700	41533.58700		-198.62198
2	-53.0857930	4	3
806.8124000	28877.66800		-159.21246
3	-44.5935040	4	3
657.6654500	20085.36600		-127.02092

COMPARING PATTERN 13-B WITH STORED PATTERN 1-B

0	-100.2900000	3	2
1995.6450000	134429.29000		-109.35000
1	-82.8971710	3	2
1643.7888000	92097.38600		-93.00014
2	-68.3478650	3	2
1350.9830000	62908.24100		-78.83497
3	-56.1751480	3	2
1107.8032000	42810.34800		-66.58641

COMPARING PATTERN 14-B WITH STORED PATTERN 1-B

0	-100.2175000	9	4
2663.8600000	195686.06000		-246.85000
1	-81.8774800	9	4
2173.1067000	132156.02000		-198.62196
2	-66.6436300	9	4
1769.6046000	88938.41600		-159.23636
3	-53.9947460	9	4
1439.3604000	59599.62000		-127.08142

COMPARING PATTERN 15-B WITH STORED PATTERN 1-B

0	64.7725000	5	3
725.6700000	35671.43900		553.15000
1	54.8673930	5	2
593.7562500	25137.25300		441.98737
2	46.4547990	5	2
491.2423000	17732.08300		352.01941
3	39.2903590	5	2
415.7713200	12514.82400		279.22194

COMPARING PATTERN 16-B WITH STORED PATTERN 1-B

```
0                    64.7725000        5          3
1360.5900000        71385.56700                  1353.15000
1                    54.5517680        5          2
1097.3899000        49217.11800                  1081.01860
2                    45.9638760        5          2
881.9667700         34078.96500                   860.73279
3                    38.7242390        5          2
705.6788400         23699.80800                   682.47288
```

COMPARING PATTERN 17-B WITH STORED PATTERN 1-B

```
0                   -75.1050000        4          3
1047.2900000        52086.31300                 -1046.85000
1                   -62.9606140        4          2
845.0372900         35610.47400                  -836.07500
2                   -52.8919200        4          2
680.2633900         24368.31800                  -665.47139
3                   -44.3851920        4          2
545.4227600         16684.28400                  -527.43413
```

COMPARING PATTERN 18-B WITH STORED PATTERN 1-B

```
0                   -75.1050000        4          3

1846.8600000        101715.29000              -1846.85000

1                   -62.9606140        4          2

1482.6974000        69586.97600               -1477.63060

2                   -52.8919200        4          2

1186.0622000        47654.42600               -1178.11180

3                   -44.3849910        4          2

944.4485400         32653.78000               -935.22135
```

COMPARING PATTERN 19-B WITH STORED PATTERN 1-B

0	-87.7900000	3	2
2646.3500000	179496.51000		-2646.35000
1	-72.2909210	3	2
2119.1856000	120260.70000		-2119.18560
2	-59.4070530	3	2
1690.7514000	80433.72300		-1690.75140
3	-48.6927470	3	2
1343.0076000	53664.31400		-1343.00760

COMPARING PATTERN 20-B WITH STORED PATTERN 1-B

0	-87.7900000	3	2
3346.8500000	256026.75000		-3346.85000
1	-72.2909210	3	2
2691.0420000	170371.33000		-2691.04200
2	-59.4070590	3	2
2157.2630000	112992.86000		-2157.26300
3	-48.6929650	3	2
1722.8527000	74609.64200		-1722.85270

STORING PATTERN 1-C WITH METRIC 1

0	-100.0000000	5	5
1600.0000000	126250.00000		-1600.00000
1	-80.4312500	5	5
1291.9493000	83607.22900		-1276.79990
2	-64.4303750	5	5
1039.6325000	55473.66000		-1015.55390
3	-51.3550660	5	5
833.0155300	36584.89500		-804.46277
4	-40.6782070	5	5
663.8711000	24015.83700		-633.04417

```
5                      -31.9671940       5         5
  527.9223200           15672.77900            -496.25565
6                      -25.5785250       4         5
  429.4896700           10153.04900            -385.12450
7                     ..-20.5322150       4         5
  351.8105800            6517.11060            -295.47272
8                      -16.7330250       4         4
  291.2102300            4135.83800            -223.19013
9                      -13.7058740       4         4
  239.5104400            2588.41930            -164.95010
10                     -11.1539660       4         4
  195.3814700            1593.24840            -118.06115
11                      -8.9987690       4         7
  158.1246600             962.41005             -80.34547
12                      -7.1752847       4         4
  127.0239500             570.57816             -50.04165
13                      -5.6296510       4         7
  100.4366100             334.37819             -25.72490
14                      -4.3171880       4         7
   77.6751510             198.50344              -6.24327
15                      -3.2007690       4         4
   66.1597750             126.40696               9.33464
16                      -2.2495026       4         4
   56.0025430              94.06272              21.76176
PRINT ØF SF ARRAY FØLLØWS
   .00       .00      .03     -.08     -.04     -.04     -.08      .03      .00      .00
```

```
   .00       .05     -.28      .62      .28      .28      .62     -.23      .05      .00
   .03      -.28     1.34    -2.40     -.81     -.81    -2.40     1.34     -.28      .03
  -.08       .62    -2.40   -41.37   -44.30   -44.30   -41.37    -2.40      .62     -.08
  -.04       .28     -.81   -44.30   -45.35   -45.35   -44.30     -.81      .28     -.04
  -.04       .28     -.81   -44.30   -45.35   -45.35   -44.30     -.81      .28     -.04
  -.08       .62    -2.40   -41.37   -44.30   -44.30   -41.37    -2.40      .62     -.08
   .03      -.28     1.34    -2.40     -.81     -.81    -2.40     1.34     -.28      .03
   .00       .05     -.28      .62      .28      .28      .62     -.28      .05      .00
   .00       .00      .03     -.08     -.04     -.04     -.08      .03      .00      .00
```

PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS
```
   .00       .00      .00      .00      .00      .00      .00      .00      .00      .00
   .00       .00     -.01      .05      .03      .03      .05     -.01      .00      .00
   .00      -.01      .12     -.47     -.33     -.33     -.47      .12     -.01      .00
   .00       .05     -.47    -5.00    -5.53    -5.53    -5.00     -.47      .05      .00
   .00       .03     -.33    -5.53    -5.91    -5.91    -5.53     -.33      .03      .00
   .00       .03     -.33    -5.53    -5.91    -5.91    -5.53     -.33      .03      .00
   .00       .05     -.47    -5.00    -5.53    -5.53    -5.00     -.47      .05      .00
   .00      -.01      .12     -.47     -.33     -.33     -.47      .12     -.01      .00
   .00       .00     -.01      .05      .03      .03      .05     -.01      .00      .00
   .00       .00      .00      .00      .00      .00      .00      .00      .00      .00
```

PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS
```
   .00      -.01      .06     -.07      .00      .00     -.07      .06     -.01      .00
  -.01       .09     -.25      .06     -.27     -.27      .06     -.25      .09     -.01
   .06      -.25      .12     1.73     2.04     2.04     1.73      .12     -.25      .06
  -.07       .06     1.73    -2.24     -.49     -.49    -2.24     1.73      .06     -.07
   .00      -.27     2.04     -.49     1.82     1.82     -.49     2.04     -.27      .00
   .00      -.27     2.04     -.49     1.82     1.82     -.49     2.04     -.27      .00
  -.07       .06     1.73    -2.24     -.49     -.49    -2.24     1.73      .06     -.07
   .06      -.25      .12     1.73     2.04     2.04     1.73      .12     -.25      .06
  -.01       .09     -.25      .06     -.27     -.27      .06     -.25      .09     -.01
   .00      -.01      .06     -.07      .00      .00     -.07      .06     -.01      .00
```

```
17                      2.4741580       5         6
   51.6688430             85.78338            31.64632
```

THE FOLLOWING SETS OF PATTERN COMPARISON DATA WERE
OBTAINED BY USING THE STORED SF ARRAY OF PATTERN 1-C
AS THE SS ARRAY DURING THE COMPARISON. THE SF ARRAY
IS SET EQUAL TO ZERO. METRIC 1 USED IN STORING
PATTERN 1-C AND IN EACH COMPARISON.

COMPARING PATTERN 2-C WITH STORED PATTERN 1-C

0	-74.8325000	3	5
805.0100000	37271.35100		-165.60000
1	-62.9520660	3	5
660.5240900	26155.32600		-133.49203
2	-52.8849570	3	5
544.2503800	18387.48100		-107.22161

COMPARING PATTERN 1-C WITH STORED PATTERN 1-C

0	-10.2800000	4	4
168.2000000	1649.37280		-165.60000
1	-8.7222020	4	7
142.7227600	1121.76880		-132.22961

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C

0	-87.7925000	2	5
1474.7400000	97960.22700		-115.60000
1	-72.2929140	2	5
1203.6468000	66686.10400		-99.90457

COMPARING PATTERN 4-C WITH STORED PATTERN 1-C

0	-74.8325000	8	5
805.0100000	37271.35500		-165.60000
1	-62.9520660	8	5
660.5241300	26155.32900		-133.49205

COMPARING PATTERN 5-C WITH STORED PATTERN 1-C

0	-87.7925000	9	5
1474.7400000	97960.23200		-115.60000
1	-72.2929140	9	5
1203.6478000	66686.11200		-99.90457

COMPARING PATTERN 6-C WITH STORED PATTERN 1-C

0	-74.8325000	5	3
805.0100000	37271.35700		-165.60000
1	-62.9520660	5	3
660.5241500	26155.33500		-133.49207

COMPARING PATTERN 7-C WITH STORED PATTERN 1-C

0	-87.7925000	5	2
1474.7400000	97960.23200		-115.60000
1	-72.2929140	5	2
1203.6469000	66686.11000		-99.90459

COMPARING PATTERN 8-C WITH STORED PATTERN 1-C

0	-74.8825000	5	8
805.0100000	37271.35800		-165.60000
1	-62.9520660	5	8
660.5241600	26155.33500		-133.49207

COMPARING PATTERN 9-C WITH STORED PATTERN 1-C

0	-87.7925000	5	9
1474.7400000	97960.23400		-115.60000
1	-72.2929140	5	9
1203.6469000	66686.11200		-99.90460

COMPARING PATTERN 10-C WITH STORED PATTERN 1-C

0	-75.0450000	3	7
1264.3300000	67682.35400		-165.60000
1	-62.9923640	3	8
1036.9625000	47369.29500		-134.75456

COMPARING PATTERN 11-C WITH STORED PATTERN 1-C

0	-100.0000000	3	8
2103.8200000	152804.61000		-65.60000
1	-81.0486140	3	8
1722.8172000	103410.96000		-66.94831

COMPARING PATTERN 12-C WITH STORED PATTERN 1-C

0	-75.0450000	7	3
1264.3300000	67682.35700		-165.60000
1	-62.9923640	8	3
1036.9628000	47369.29900		-134.75456

COMPARING PATTERN 13-C WITH STORED PATTERN 1-C

0	-100.0000000	8	3
2103.8200000	152804.67000		-65.60000
1	-81.0486140	8	3
1722.8183000	103411.04000		-66.94831

COMPARING PATTERN 14-C WITH STORED PATTERN 1-C

0	64.7575000	4	5
1042.7600000	53739.85500		1034.40000
1	54.2840500	4	4
847.6561100	37045.83600		825.37041

COMPARING PATTERN 15-C WITH STORED PATTERN 1-C

0	-75.0450000	3	4
2166.3200000	125771.29000		-2165.60000
1	-62.9923640	3	3
1741.6012000	85761.09300		-1735.80320

COMPARING PATTERN 16-C WITH STORED PATTERN 1-C

0	-100.0000000	3	3
4565.6000000	378829.72000		-4565.60000
1	-81.0486140	3	3
3701.5022000	251791.38000		-3701.50220

COMPARING PATTERN 17-C WITH STORED PATTERN 1-C

0	90.1750000	6	5
1342.7600000	85282.23200		1334.40000
1	73.2437350	6	5
1087.0550000	56889.46700		1064.77060

COMPARING PATTERN 1-C WITH STORED PATTERN 1-C USING METRIC 5

0	-15.0000000	5	5
270.1200000	3285.90900		-247.64000
1	-11.1560750	4	5
205.5072900	1801.46880		-172.62121

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C USING METRIC 5

0	-125.5750000	3	5
2192.6200000	195415.22000		-147.64000
1	-93.6965500	2	5
1607.9797000	108667.84000		-123.12132

COMPARING PATTERN 4-C WITH STORED PATTERN 1-C USING METRIC 5

0	-100.5750000	8	5
1214.0600000	68741.89500		-247.64000
1	-73.1376060	8	5
899.4278900	39995.04500		-177.67122

GE/EE/63-11

COMPARING PATTERN 2-C WITH STORED PATTERN 1-C USING METRIC 8

0	-76.3775000	3	5	
1010.5900000	45168.60900			-206.62000
1	-62.0024250	3	5	
792.8802400	28804.94200			-159.50983

COMPARING PATTERN 2-C WITH STORED PATTERN 1-C USING METRIC 3

0	-99.0800000	3	5	
1014.9000000	60565.60600			-206.62000
1	-79.2795240	3	6	
788.7462400	38326.73600			-155.72224

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C USING METRIC 2

0	-101.3775000	3	5	
1805.6400000	134701.10000			-106.62000
1	-79.4274390	3	5	
1404.8701000	83754.91300			-94.85986
2	-62.1156180	2	5	
1095.1132000	52032.70000			-83.61499

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C USING METRIC 3

0	-113.0175000	2	5	
1864.9300000	151759.33000			-156.62000
1	-88.3443450	2	5	
1442.0625000	92415.03400			-127.18483
2	-68.8552490	2	5	
1123.6107000	56139.67500			-102.80793

COMPARING PATTERN 4-C WITH PATTERN 1-C USING METRIC 2

0	-76.3775000	8	5	
1010.5900000	45168.61200			-206.62000
1	-62.0024250	8	5	
792.8302400	28804.94200			-159.50983

COMPARING PATTERN 4-C WITH PATTERN 1-C USING METRIC 3

0	-99.0800000	8	5	
1014.9000000	60565.61000			-206.62000
1	-79.2795260	8	5	
788.7462400	38326.74200			-155.72224

COMPARING PATTERN 5-C WITH PATTERN 1-C USING METRIC 2

0	-101.3775000	8	5
1305.8400000	134701.21000		-103.62000
1	-79.4274330	8	5
1404.3707000	33754.92100		-94.85989

COMPARING PATTERN 5-C WITH PATTERN 1-C USING METRIC 3

0	-113.0175000	9	5
1304.0300000	151759.44000		-156.62000
1	-83.3443400	9	5
1442.0121000	32415.04000		-127.13430

COMPARING PATTERN 2-C WITH PATTERN 1-C USING METRIC 5

0	-100.5750000	3	5
1214.0600000	68741.89100		-247.64000
1	-78.1376150	3	5
399.4279200	39995.04200		-177.67123
2	-60.9514330	3	5
681.5403800	23642.50200		-126.62112

COMPARING PATTERN 1-C WITH PATTERN 1-C USING METRIC 4

0	-8.6300000	4	4
139.4000000	707.16340		-83.56000
1	-7.7533700	4	4
125.3206000	571.53406		-75.12044

COMPARING PATTERN 2-C WITH PATTERN 1-C USING METRIC 4

0	-49.1900000	3	5
469.2400000	17199.16100		-83.56000
1	-44.2218100	3	5
421.8467600	13900.37700		-75.12044

COMPARING PATTERN 3-C WITH PATTERN 1-C USING METRIC 4

0	-50.6200000	2	4
827.8400000	35309.15000		-83.56000
1	-45.5073800	2	4
744.2231600	28536.88500		-75.12044

COMPARING PATTERN 4-C WITH PATTERN 1-C USING METRIC 4

0	-49.1900000	8	5
469.2400000	17199.16300		-83.56000
1	-44.2218100	8	5
421.8467600	13900.37900		-75.12044

COMPARING PATTERN 5-C WITH PATTERN 1-C USING METRIC 4

```
0                   -50.6200000        9        4
327.8400000         35309.15700              -83.56000
1                   -45.5073800        9        4
744.2281600         28536.89100              -75.12044
```

COMPARING PATTERN 18-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                   -49.8325000        3        6
384.9900000         10314.24400              -165.60000
1                   -43.9489410        3        6
331.2192300         7841.36290              -132.86085
```

COMPARING PATTERN 19-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                   -49.8825000        3        5
601.7800000         18979.11500              -165.60000
1                   -43.9489410        3        5
525.2548200         14664.08300              -133.49209
```

COMPARING PATTERN 20-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                   -62.3825000        3        5
602.7200000         23979.10600              -165.60000
1                   -53.9239410        3        5
517.1675100         18022.02400              -133.49207
```

COMPARING PATTERN 21-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                   -62.3825000        3        5
966.3200000         38647.86100              -965.60000
1                   -53.2926910        3        5
789.4223400         27137.99000              -773.15447
```

COMPARING PATTERN 22-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                   65.1750000         5        5
325.7200000         17455.86200              234.40000
1                   55.1869850         5        5
269.3033400         12536.39400              186.97039
```

COMPARING PATTERN 23-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                   -75.0450000        3        4
2287.7200000        139077.79000             -1765.60000
1                   -62.9923640        3        3
1868.9469000        96690.35600              -1416.60390
```

COMPARING PATTERN 24-C WITH STORED PATTERN 1-C USING METRIC 1

0	90.1750000	5	5
2123.8400000	122282.77000		-565.60000
1	73.8744850	5	5
1783.4882000	87486.71800		-456.47961

STORING PATTERN 1-D USING METRIC 1

0	-75.0000000	6	3
1875.0000000	103437.50000		-1875.00000
1	-63.6375000	8	2
1527.1801000	71554.22100		-1513.29310
2	-53.9875250	8	2
1240.8355000	49683.63000		-1218.48360
3	-45.7777230	8	2
1005.1438000	34632.49600		-978.16541
4	-38.7808940	8	2
812.0890900	24238.96400		-782.21843
5	-32.8072800	8	2
659.8041300	17036.07100		-622.42403
6	-27.6982120	8	2
543.9840500	12025.96600		-492.08947
7	-23.3208510	8	2
454.4441900	8528.03590		-385.76653

8	-19.5638370	8	2
395.2107000	6076.70940		-299.62004
9	-16.3336910	8	2
353.8073100	4352.53800		-228.23857
10	-13.5518380	8	2
317.0074800	3135.58280		-170.48075
11	-11.1521270	8	2
283.1655700	2273.87790		-123.35095
12	-9.1207400	3	7
252.9405600	1662.02640		-84.89712
13	-7.7058402	3	4
225.4970600	1226.63700		-53.52859
14	-6.4744520	3	7
200.3324400	916.38781		-27.94868
15	5.6016670	5	4
177.2719400	695.23644		-7.10017
16	5.6812710	5	4
156.1504100	537.75716		9.87932

PRINT OF SF ARRAY FOLLOWS

```
 .00   .10  -.66   2.42  -2.87  -2.87   2.42   -.66    .10    .00
 .04  -.40  2.35  -7.16 -38.60 -38.60  -7.16   2.35   -.40    .04
-.03   .35 -2.08 -38.79  -4.72  -4.72 -38.79  -2.08    .35   -.03
-.36  2.16 -6.52 -37.98  -1.34  -1.34 -37.98  -6.52   2.16   -.36
 .38 -2.43 -36.99 -9.19    .63    .63  -9.19 -36.99  -2.43    .38
2.10 -5.47 -42.31 -41.07 -43.16 -43.16 -41.07 -42.31  -5.47   2.10
-3.25 -37.59 -5.02  -.84  -1.42  -1.42   -.84  -5.02 -37.59  -3.25
-.61 -44.80  -.13   .63    .34    .34    .63   -.13 -44.80   -.61
-2.98 -38.80 -3.15   .66   -.14   -.14    .66  -3.15 -33.80  -2.98
1.55 -3.64  1.60   -.31    .04    .04   -.31   1.60  -3.64   1.55
```

```
PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS
   .00     .00   -.03    .21   -.52   -.52   -.21   -.03    .00    .00
   .00    -.02    .20  -1.18  -4.48  -4.48  -1.18    .20   -.02    .00
   .00     .04   -.45  -4.49   -.97   -.97  -4.49   -.45    .04    .00
  -.02     .19  -1.12  -4.42   -.36   -.36  -4.42  -1.12    .19   -.02
   .04    -.47  -4.34  -1.64   -.20   -.20  -1.64  -4.34   -.47    .04
   .19   -1.04  -5.08  -4.98  -5.15  -5.15  -4.98  -5.08  -1.04    .19
  -.54   -4.40   -.98   -.33   -.39   -.39   -.33   -.98  -4.40   -.54
  -.34   -5.30   -.29    .08    .04    .04    .08   -.29  -5.30   -.34
  -.53   -4.52   -.54    .06    .00    .00    .06   -.54  -4.52   -.53
   .13    -.59    .14   -.01    .00    .00   -.01    .14   -.59    .13
PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS


  17                   5.6897410        5        4
   136.8127400          425.93198               23.69334
```

COMPARING PATTERN 1-D WITH STORED PATTERN 1-D USING METRIC 4

```
0                    -13.0100000      5        3
   314.0800000          2707.34920           -114.04000
1                    -11.6959900      5        3
   282.3579200          2188.08040           -102.52196
```

COMPARING PATTERN 2-D WITH STORED PATTERN 1-D USING METRIC 4

```
0                    -49.8700000      8        8
   1009.7800000         37492.32400          -114.04000
1                    -44.8331300      8        8
   907.7922200          30301.33000          -102.52196
```

COMPARING PATTERN 3-D WITH STORED PATTERN 1-D USING METRIC 4

```
0                    -52.3500000      2        3
   1215.2400000         48126.32300          -64.04000
1                    -47.0626500      2        3
   1092.5004000         38895.73600          -57.57196
```

COMPARING PATTERN 4-D WITH STORED PATTERN 1-D USING METRIC 4

```
0                    -49.8700000      8        8
   768.4400000          25425.33700          135.96000




1                    -44.8331300      8        8
   690.8275600          20548.77900          122.22804
```

COMPARING PATTERN 5-D WITH STORED PATTERN 1-D USING METRIC 4

0	-50.6300000	5	5
799.5600000	27107.33100		-714.04000
1	-45.5163700	5	5
718.8044400	21908.16700		-641.92196

COMPARING PATTERN 6-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	8
1182.9600000	46829.32500		-64.04000
1	-47.0626500	2	8
1063.4807000	37847.49900		-57.57196

COMPARING PATTERN 7-D WITH STORED PATTERN 1-D USING METRIC 4

0	-50.6600000	9	4
993.3000000	36860.33000		35.96000
1	-45.5433400	9	4
892.9767000	29790.55100		32.32804

COMPARING PATTERN 8-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1397.0200000	57344.32600		-214.04000
1	-47.0626500	2	3
1255.9207000	46345.73800		-192.42196

COMPARING PATTERN 9-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1293.5000000	52042.32600		-114.04000
1	-47.0626500	2	3
1162.8563000	42060.65700		-102.52196

COMPARING PATTERN 10-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1084.2200000	41684.32300		85.96000
1	-47.0626500	2	3
974.7137800	33689.30700		77.27804

COMPARING PATTERN 11-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1192.7200000	47109.32300		-114.04000
1	-47.0626500	2	3
1072.2552000	38073.79900		-102.52196

COMPARING PATTERN 12-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1381.7600000	56389.32300		85.96000
1	-47.0626500	2	3
1242.2016000	45573.90300		77.27804

COMPARING PATTERN 13-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1385.0400000	56616.32300		-14.04000
1	-47.0626500	2	3
1245.1503000	45757.36600		-12.62196

COMPARING PATTERN 14-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1489.5800000	61906.32300		-214.04000
1	-47.0626500	2	3
1339.1317000	50032.74900		-192.42196

COMPARING PATTERN 15-D WITH STORED PATTERN 1-D USING METRIC 4

0	-50.6300000	5	5
1220.8800000	48173.32300		85.96000
1	-45.5163700	5	5
1097.5708000	38933.72100		77.27804

COMPARING PATTERN 16-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	8
1213.8200000	48026.32300		335.96000
1	-47.0626500	2	8
1091.2239000	38814.91900		302.02804

COMPARING PATTERN 17-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1443.8600000	59861.32200		-164.04000
1	-47.0626500	2	3
1298.0298000	48379.97300		-147.47196

Vita

William L. Harrison was born on 2 July 1929 in Janesville, Wisconsin, the son of Vern P. Harrison and Ruby M. Harrison. After graduating in 1947 from Fairfield Community High School, Fairfield, Illinois, he enlisted in the U.S. Navy. In 1951 he received an appointment to the U.S. Naval Academy, from which he was graduated in June, 1955, with the degree of Bachelor of Science. After accepting a commission as Lieutenant in the U.S. Air Force, he underwent flight training and then performed flying duties in the Air Defense Command and the Pacific Air Forces prior to entering the Air Force Institute of Technology in February, 1962.

This thesis was typed by Mary Marlene Harrison

Vita

William L. Harrison was born on 2 July 1929 in
Janesville, Wisconsin, the son of Vern P. Harrison
and Ruby M. Harrison. After graduating in 1947 from
Fairfield Community High School, Fairfield, Illinois,
he enlisted in the U.S. Navy. In 1951 he received an
appointment to the U.S. Naval Academy, from which he
was graduated in June, 1955, with the degree of
Bachelor of Science. After accepting a commission
as Lieutenant in the U.S. Air Force, he underwent
flight training and then performed flying duties in
the Air Defense Command and the Pacific Air Forces
prior to entering the Air Force Institute of Technology
in February, 1962.

This thesis was typed by Mary Marlene Harrison